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AFGL ROCKET- AND SHUTTLE-BORNE PARTICLE BEAM EXPERIMENTAL PROGRAM

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1. INTRODUCTION

Charged particle beams, aside from their use as tools for magnetospheric research, have been used principally to study vehicle charging and discharging in the ambient environment and for active control of vehicle potential. These studies have been limited to rocket flights in the near-earth space except for the spacecraft charging experiment aboard the SCATHA satellite near geosynchronous altitude. However, a knowledge of vehicle potential behavior is not enough to evaluate military uses of particle beams. It is essential to know the physical principles controlling beam emission and propagation, including the interaction of the beam with the in situ plasma, neutrals, and electric and magnetic fields, and the effect of the vehicle on beam propagation. This document details a program for a systematic set of experiments to determine these relations.

The first artificial ejection of an energetic particle beam into near-earth space was carried out a little over ten years ago[1]. Since that time a number of such experiments have been conducted. Winckler[2] recently reviewed the accomplishments in this field up to February 1980. The experimental evidence presented in that article leaves no doubt as to the realizability of energetic particle beam ejection into, and propagation through, the ionosphere and magnetosphere. However, many questions remain as to the limits nature imposes on such beams. These questions include the following: 1) What special conditions on the emitting body must be fulfilled, as a function of altitude, beam energy and current, in order to permit beam ejection? 2) To what extent does the beam return to the emitting body and how can this be prevented? 3) How far can such beams propagate without breaking up due to the interaction with in situ particles and fields, or due to self fields? 4) What electromagnetic frequencies are generated, and radiated, due to the interactions of the beam with the surrounding environment and emitting body? Carpenter et al.[3] have addressed some of these questions and concluded that beams of significant intensity (e.g. tens of amperes) can be ejected and propagated in the magnetosphere for distances significantly in excess of those previously achieved.

In this report we describe an experimental program which will provide a series of rocket and Shuttleborne measurements to characterize beam propagation in the upper atmosphere. These rocket and Shuttle payloads extend beam ejection and propagation from the energies and power levels used in past rocket experiments, and planned for the Shuttle by NASA experimenters, to particle energies and power levels of potential applicability to military systems. In addition to electron and ion accelerators, the use of neutral beam systems also is planned. The proposed experiments are of increasing complexity and are designed to build on the knowledge gained from earlier experiments, and whenever possible to utilize the hardware previously developed.

The results of these rocket and shuttle investigations will provide information essential for a meaningful assessment of the potential impact of particle beams on present and future military systems. While it is not the purpose of the experimental plan described in this report to develop military concepts, it is, nevertheless, important to consider the possible uses of particle beams in space in order to plan appropriate experiments. Some relevant military applications are discussed in Section 2. The ideal characteristics of the ejected particles for the various applications differ considerably as far as particle type, power, energy, current, pulse duration, and beam spread are concerned. Hence, the inherent problems of beam ejection and propagation may differ, not only in degree, but in a fundamental manner, for each application.

As part of the preparation of this experimental plan we have reviewed the work performed and the plans of the domestic and foreign civilian communities in regards to particle beam experimental programs. This review is presented in Section 3 to this report. The accelerators presently planned for charge ejection experiments aboard the Space Shuttle are limited to voltages less than 20 kV and powers less than 25 kW. However, higher voltages and currents are of military interest. The effects of higher currents and energies may be of a fundamentally different nature so as to make extrapolation from the results of the lower voltage and current experiments unreliable and/or meaningless. As part of this program experiments will be conducted at substantially higher voltages and power levels than present civilian plans envision.

The five rocket payloads and the six Shuttleborne experimental payloads which constitute the proposed experimental program are described in Section 4. One should understand that the results obtained in the early experiments may require modifications in the plans for the later ones. A cost estimate and schedule of the proposed experimental plan is provided in Section 5.

Appendix A provides an overview of the limitations placed on space experiments by international treaty and environmental impact considerations and crew and vehicle safety. Appendix B describes the support the experiments can derive from existing Space Test Program (STP) equipment and the constraints which limit experiments performed or based on shuttle operations. Equipment procured by the STP of the Air Force and NASA programs which can be of use in the proposed experiments is also identified.

1.1 Technical Objectives and Program Overview

The main objective of the program outlined in this report is to provide information of the operation of space-based accelerators for an extended range of operating conditions. From a study of proposed particle beam experiments, it was found that no plans exist for using particles with energies above 20 keV in the foreseeable future. A plan has therefore been developed to study the relevant physics of particle beam emission and propagation in a time frame commensurate with that reasonably required to develop the capability to deploy beam weapons in space. While the plan limits the ejection of beams to altitudes attainable by the Space Transportation System, beam propagation can be studied for the entire trapping regions, since particles injected at high magnetic latitude reach high altitudes at low latitudes due to the guiding influence of the terrestrial magnetic field.

These experiments are designed to progress with electron, ion, and neutral beams of increasing energies at a rate at which the necessary accelerators and diagnostic equipment can be provided. In addition, the experiments are designed to be managable from a manpower and cost point-of-view. In each case, the accelerator proposed for a shuttle flight is first operated aboard a rocket payload in a mode which fully tests and diagnoses the performance of the accelerator. This information will then be used to predict the operation of the full systems as far as the beam emittability, propagation, and reaction back on the operating system are concerned. In this way, the shuttle flight would be performed in a manner which is safe for the inflight crew and provides a maximum of useful information.

It is important to note that even for systems which use neutral beams, the understanding of the operation of charged particle beams is necessary in order to understand the behavior of the small charged portion of the beam, as well as the charged return current created by the propagation and interaction of the neutral beam with the ambient media. In addition, an understanding of the radiation produced by the interaction of the beams will provide a method of recognizing the propagation of a particle beam and, thus, the possibility of evasive action or the protection of sensitive equipment.

The proposed plan calls for the launching of five rockets and six satellites during a period of ten years and would require an expenditure of about 85 million dollars over a 12 year period. The cost figures presented in Section 5 are estimates in 1980 dollars.

While the development of space based particle-beam weapons would add considerable urgency to the timely execution of the plan, the knowledge to be developed is required even in the absence of the development or deployment of particle-beam systems. For example, the knowledge to be gained from the program is required to identify and analyze the deployment of particle beams, clandestine or overt, by other powers. Furthermore, other uses of particle beams have been identified and some applications, such as the use of beam ejection to overcome satellite charge-up, are already in limited use. An understanding of the physics underlying the phenomenology could lead to greater efficiency and possible system development for long-lived satellites.

2. RELEVANCE

Military operations assigned to the Air Force are strongly dependent on space-borne systems. This is particularly true in the areas of detection, surveillance, communications, and weather forecasting. It is, therefore, essential to understand the vulnerability of such systems to particle beams and the defensive measures which can be used to minimize the vulnerability of existing and future systems.

For this purpose it is necessary to consider vulnerability both to natural effects and man-made threats. The SCATHA experiment has shown that particle beams can be used to alleviate naturally induced conditions which tend to damage space-borne systems[4]. Conversely, such beam systems have the potential as weapons to disable or destroy spaceborne surveillance systems, as well as weapon systems which traverse space on their way to their target. Table 1 lists some potential military applications of space-based particle beam systems. It is not the purpose of this report to evaluate the potential military uses of beam systems. Suffice it to say, the applications briefly described in the following vary from ones already in use to ones not likely to come into operation in the present generation.

2.1 Vehicle Potential Control

Spacecraft can, at times, develop high potential which can lead to arcing during discharge. Differential voltages of tens of thousands of volts have developed on satellites at synchronous orbit, particularly during solar eclipses. Subsequent discharge has resulted in the upset of digital logic circuits, as well as catastrophic failure of components. These effects have been found to be due to intense fluxes of energetic particles associated with geomagnetic substorms. The ejection of streams of energetic particles from a spaceborne platform could cause similar effects that must be overcome if space vehicles are to be used as platforms for particle beam weapon systems. It has been found that the emission of even small currents of low energy particles is useful in alleviating these effects.

While to date, serious deterioration of spacecraft systems due to spacecraft charging has been observed only at very high altitudes (near-synchronous), theory predicts that the effect becomes more serious with the increasing size of the satellite. Therefore, large objects in near-earth space, which might have important military value, may be vulnerable to bombardment by energetic particle beams.

TABLE 1

APPLICATIONS OF SPACE BASED BEAM SYSTEMS

Modification of Vehicle Potential

- Degradation of space system performance
- Mitigation of damage to friendly space system

Atmospheric Modification

- Degradation of satellite communications
- Degredation of reconnaissance systems and high altitude intercept system performance

Damage to Enemy Space Based Systems

- High power beams

Beam Detection and Diagnostics

2.2 Atmospheric Modification

The ion density of the ionosphere controls the transmittability and reflectability of radio waves, and, if artificially modified, would possess characteristics other than those normally expected. In addition to increasing the level of the electron density, particle beams could also be used to provide enhanced electron structure which will produce additional noise in communication links.

Enhanced energy deposion in the upper atmosphere can affect reconnaissance satellites as well as communications systems. Programs at AFGL have clearly shown the enhancement of optical emissions at important wavelengths associated with increased energy deposition and the importance of spatially structured optical backgrounds in assessing the impact on potential system performance.

2.3 Damage to Enemy Space Based Systems

High power particle beams have potential utility as antisatellite or anti-missile weapons. Heavy particle beams with MeV energies and current densities of amperes-cm^{-2} could produce surface blow off which could damage sensitive detectors and optical surfaces on reconnaissance satellites or result in trajectory degradation or destruction on reentry. 100 MeV electron beams could penetrate thin wall satellites and produce additional penetrating x-radiation which could damage internal electronic components.

2.4 Beam Detection and Diagnostics

The possibility that beam weapon systems might be employed in space makes it necessary to be able to detect and diagnose the use of such beams. Such detection systems will eventually require both a high degree of sophistication and a compactness to permit their routine use in space-borne systems. The essential physics underlying their operation is identical to that to be used as diagnostics in the program proposed herein to study particle beams in space. We shall, therefore, not address the details of detection and diagnostics systems here, but make reference to the experimental payloads proposed in Section 4.

3. REVIEW OF PREVIOUS AND PLANNED CHARGE PARTICLE BEAM INVESTIGATIONS

This section includes a survey of those charged particle investigations performed or planned which are relevant to the proposed experimental program. The intent of this review is to document the areas under study by other investigators rather than to provide an exhaustive literative review. Also included are a description of the SCATHA satellite experiment and plans for civilian use of the Shuttle.

3.1 Survey of Rocketborne Experiments

During the last decade electron beams have been ejected successfully into the upper atmosphere and ionosphere on more than 25 flights at altitudes from 100 to 350 km. These flights, which are summarized in Table 2, have produced a large body of knowledge concerning the emission and propagation of electron beams at low altitudes and, generally, low beam voltages (<50 KeV) and currents (<1 A). The range of power used in these experiments shows that beams can be ejected and the emitting vehicle successfully neutralized, even at high current levels (25 A) and low ambient plasma density ($\simeq 10^5 cm^{-3}$ at 135 km altitude). While it was initially assumed that this might be a problem, in no case has this been found to be so. The vehicle neutralization found in these experiments has been interpreted to be the result of beam and return current ionization (ECHO II and POLAR 5 experiments) [5,6] and beam-plasma discharges (Bernstein laboratory experiments and possibly the POLAR 5 experiment) [7,6]. In addition to atmospheric secondary ionization, ionization also results from interaction of the primary beam with the vehicle body and neutral gases in the vicinity. The general conclusion [6,8] is that the vehicle is surrounded by a hot plasma which supports the neutralization. The development of a beam-plasma discharge in space at higher current levels is of great interest and ARAKS II rocket experiments to explore this further are being considered.

A feature of the problem of beam emission that is still unresolved is the level of the resulting vehicle potential. This quantity is difficult to measure due to the induced plasma environment surrounding the vehicle. In one experiment in the Norwegian POLAR 5 series, which employed a mother-daughter arrangement using an electric field double probe, a potential of several hundred volts to 1 kilovolt was inferred for a vehicle emitting an electron beam of 10 keV at 100 mA. This type of free-flyer approach is to be continued in the Norwegian POLAR and the Minnesota ECHO

TABLE 2 ELECTRON BEAM ROCKET EXPERIMENTS

NAME	DATE & LAUNCH SITE	L	MAJOR RESULTS	CURRENT (A)	ENERGY (kev)
HESS Artificial Aurora Experiments	69, Wallops Is. 71, Kauai	2.5	Auroral Streaks Conj. Auroral Streak	0.5 0.5	20 20
ECHO Series (Winckler)	70, Wallops Is. 72, Ft. Churchill 74-79, Poker Flat	2.5 8.5 5.5	Echoes No Echoes Echoes, EM Waves	0.1 0.1 0.1-0.8	40 40 40
Feyerwerk	73, Russia	2	Auroral Streaks	0.5	9
Zarnitza	73, 75 Russia		Auroral Streaks Beam Plasma Discharge	2.5, .5	7-9, 10
PRECEDE-EXCEDE Series (AFGL)	74, White Sands 75,76,79, Poker Flat	1.75 5.5	Auroral Streaks Auroral Streaks	0.8 1 - 25	3 3
ARAKS (2)	75, Kerguelen	3.6	Conj. Echoes	0.5	15, 27
Japan (K) Series (4)	75-78 Kagoshiwa		Rocket Charging Artificial Airglow	.002-.35	.2-5
Norwegian POLAR (2) (Mother-Daughter)	Andoya		Beam-Plasma Evidence	0.1	10
EIIB Series (Canada, Minn, NOAA)	77,78 Churchill	8.5	Double Layer Search Beam Plasma	0.001, 0.01, .08	2, 4, 8

series. A recent rocket experiment conducted by the Air Force Geophysics Laboratory[9] has studied the environmental effect on ejection of beams of both positive and negative particles. For ion ejection it was found that the vehicle potential depended on the ambient plasma density but was independent of neutral density and angle between the vehicle axis and the earth's magnetic field. On the other hand, in the EXCEDE experiments, in which 10 to 25 amperes were emitted at 3 KeV, no charge-up potential greater than about 200 volts has been noted. In addition to the difficulties encountered in measuring the potential, it has been found difficult to predict the vehicle potential, mainly due to the complexity of the surroundings and the complex geometry of the rocket payload. Measurements for simple geometrical and electrical emitters in a variety of plasma conditions can form a systematic approach to the solution of this important problem.

Experiments designed to study the stability in space of the emitted beams have generally been very successful. Early in the planning of these experiments it was expected that these beams would be unstable due to the great number of potential plasma instabilities. However, this has not been the case, as revealed mainly by the EXCEDE and ECHO series. In the EXCEDE emissions the far field beam dimensions closely agree with the single particle calculations even at the highest altitudes (~135 km and 10 A). In the ECHO series the stability was confirmed for very long paths (up to 150 earth radii). For example, in ECHO IV[10], at an L-shell of ~6, up to five bounces were observed for a single pulse, with a portion of the pulse retaining its initial energy and coherence. In addition, it was found in ECHO III[11] that the return echoes were concentrated in a shell perpendicular to the drift direction only a few Larmor radii thick.

The propagation of a beam through the atmosphere has been found to generate a complex number of waves as revealed by in situ and remote (ground) measurements. These waves have frequencies extending to 60 MHz and include waves at the plasma frequency, the cyclotron frequency and its harmonics, and in the lower hybrid region. However, these waves contain only a few percent or less of the beam energy and are not considered to be the result of a catastrophic energy loss. In addition, no measureable waves have been positively identified which arise from locations remote to the immediate surroundings of the vehicle. In order to sort out the various mechanisms by which these waves are generated it is necessary to make measurements inside and adjacent to the beam. Studies of wave phenomena are planned for the active programs of the various rocket groups. In addition, laboratory work on waves generated by beam-plasma discharges is to be continued at the Johnson Space Center.

The scattering interactions of the beam with the atmosphere appear to be generally understood, especially for processes which are single particle collisions. Monte Carlo calculations have predicted the times, locations, and details of reflected beam echoes quite accurately as revealed by the ECHO series. However, the analysis of the ARAKS experiments[12] revealed that "downward" injections were rocket altitude dependent, due presumably to local rocket gas effects. Optical and radar measurements are generally in agreement with predicted results. Presumably some rocket measurements will now concentrate on cooperative interactions such as beam plasma discharges. The critical current, I_c (in mA), for a beam-plasma discharge is predicted, on the basis of the chamber experiments at the Johnson Space Center, to be dependent upon the beam and experimental parameters, thusly

$$I_c = \frac{K\,V^{3/2}}{B^{0.7}\,PL} ,$$

where K is 2×10^{-4} amp $(\text{gauss})^{0.7}$ torr -m $(\text{kV})^{-3/2}$, V is the particle energy in kilovolts, B the magnetic field in gauss, P the pressure in torr, and L is a characteristic dimension of the experiment in meters. In the laboratory, L was the distance of separation between the anode and the collector plate. For a 1.5 kilovolt beam, with a superimposed field of 1.14 gauss, a chamber pressure of 10^{-5} torr, and a distance between the beam and collector of 20 m, the critical current was found to be 2 mA. It is not clear in a free-field experiment what length is to be ascribed to L. For the EXCEDE II Test field experiment[13], the parametric values were 3 kilovolts, 10^{-5} torr, and 0.6 gauss field. If the electron gyroradius or the rocket dimension is the characteristic length (~few meters), then a beam plasma discharge should have been seen for currents larger than about 50 mA. In EXCEDE II Test, no such phenomenon was noted for currents up to 10 amperes.

In addition to experiments to study beam propagation, beam interaction, and vehicle charging, experiments have also been conducted (and planned to be continued) to study the magnetosphere. In particular, the ECHO series in the auroral region and the Norwegian POLAR series are studying the electric fields in the upper atmosphere. Potential rocketborne experiments which may take place in the near future (other than those discussed in this report) are summarized in Table 3.

From this short review of rocketborne experiments, we conclude that electron beams can be ejected from the vehicle and propagated through the upper ionosphere and magnetosphere. However, in almost every experiment, certain features appear for which no satisfactory explanations have been found. For example, in ECHO I[14], the return echoes had only 10% of the expected flux and, in addition, doublet echoes were observed; in ECHO II[5], no echoes were observed (presumably due to the high L shell of the ejection location); in ECHOES IV[10] and V, the return of echoes (which were assumed to be magnetically mirrored) did not produce visible streaks in the atmosphere as predicted, presumably due to equatorial pitch angle scattering. Other examples of questions are found in the e-m waves which are expected from the beam propagation. In particular, was the halo around the vehicle in the Norwegian POLAR 5 experiment actually due to a beam plasma discharge? These unexplained features point out that more experimentation is needed before we can satisfactorily predict the motion of beams in space and their resultant characteristics.

3.2 SCATHA Satellite Experiment

This satellite was designed and flown for the specific purpose of studying Spacecraft Charging At High Alititude (SCATHA) near geosynchronous altitude. It contained both electron and ion guns. The electron gun was designed to provide six levels of electron energy (3, 1.5, 0.50, 0.30, 0.15, and 0.05 keV) and six levels of beam current (13, 6, 1, 0.1, 0.01 and 0.001 mA[16]). The ion gun characteristics are given in Table 4[17]. Cohen et al.[18] have employed these guns to suppress SCATHA's charge-up to acceptable levels. While the ion engines on the ATS-5 and ATS-6 have been successfully used to clamp the environmentally induced potential of these spacecrafts[19,20], ion and electron guns have been employed on the SCATHA satellite.

TABLE 3 POTENTIAL ROCKETBORNE EXPERIMENTS

- BEAM EJECTION AND VEHICLE NEUTRALIZATION

  Beam-Plasma Discharge — ARAKS

- VEHICLE POTENTIAL DETERMINATION

  Mother-Daughter Experiments — Norwegian POLAR Series

- BEAM STABILITY AND COHERENCE OVER LONG PATHS

  Beam Detection — ECHO Program
  Beam-Plasma Discharge — ARAKS

- PLASMAS AND WAVE GENERATION

  Beam-Plasma Physics — ARAKS II
  Plasma Diagnostics — ECHO

- MAGNETOSPHERIC PROPERTIES

  "Electric Double Layers" — Canadian "EIIB" Series
  — Norwegian POLAR Series
  E-Fields — Echo Series

TABLE 4 SCATHA ION GUN CHARACTERISTICS

PARAMETER	REQUIREMENT	CHARACTERISTIC
Ion Beam		
Current, mA	0.3 to 2.0	0.3 to 2.0
Energy, keV	1 to 2	1 and 2
Input power, W		
Maximum startup	60	55
1 mA beam, 1 keV	25	30
2 mA beam, 2 keV	--	45
Full beam and biased neutralizer	--	55
Expellant	Noble gas	Xenon
Weight, kg	7.8 maximum	7.4
Operating life, hr	300 minimum	>300
Neutralizer		
Control	Ion beam on or off	On/off control
Emission range	2 μA to 2 mA	2.5 μA to 2.5 mA
Biasing	-1 kV to + 1 kV	-1 kV to +1 kV in 10 steps

On March 30, 1979 an electron gun was operated on the satellite before the satellite entered eclipse and during the time of eclipse. Spacecraft frame, and surfaces on the spacecraft, went positive with respect to points 50 meters from the satellite when the gun was operated. Depending on ejected electron currents and energies, spacecraft frame-to-ambient-plasma potential diferences between several volts and 3 kV were generated. Simultaneously, lower potential differences were created between the satellite and a point 3 meters from the satellite. Sample surface potentials were measured during gun operations. When the electron gun was turned off, the vehicle frame swung sharply negative. Arcing was detected by pulse monitors in several electron beam modes of operation. The ejection of a beam of 6 mA of 3 keV electrons caused three distinct payload failures and created a transient problem in the telemetry system. Analytical and modeling techniques have been used to examine possible spacecraft and payload responses to the electron beam ejection which might have contributed to the arcing and payload failures. These are discussed further in Reference 18.

3.3 Civilian Community Plans for Shuttle Use

The particle accelerators planned for Shuttle flight by the civilian community and the salient characteristics of the accelerators are listed in Table 5. It is our aim to use the results obtained from these experiments and to design future experiments which will expand on this knowledge, particularly in the directions of Air Force and Department of Defense interests.

The French experiment PICPAB[21] is to use low current, short duration (10 μsec) pulses to study the quasilinear response of the space plasma in the vicinity of the shuttle. From this they hope to obtain some knowledge on neutralization processes. The accelerator can be insulated from the shuttle ground or its potential be allowed to float. The potential measurements are to be limited to ± 200 V. Return current measurements will be carried out with the accelerator grounded to the shuttle and with it floating. Plasma measurements will be made with a high frequency quadrupole probe, an electrontemperature probe, and antennas with frequency ranges up to 700 KHz.

TABLE 5 PLANNED CIVILIAN COMMUNITY CHARGED PARTICLE ACCELERATORS ON STS

EXPERIMENTER	ELECTRON ACCELERATOR			ION ACCELERATOR	
	VOLTAGE	CURRENT	PULSE LENGTH	ION	POWER LEVEL
CNRS/CNET Orleans, France C. Beghin	10 kV	100 mA	20 μs	H_2^+ H^+	8 kV 3 mA
Utah State University Peter Banks	1kV	100 mA	600 ns-107 s	--------------	
University of Tokyo T. Obayashi Present System	7.5 KV max	1.5 A	10 ms-1 sec	A^+	2 kJ - 1 ms pulses 250V
University of Tokyo T. Obayashi Potential Improvement	1-20 kV	1-25 A	10 ms-1 sec	A^+ H^+	2 kJ - 1 to 2ms pulses 250V

The Utah State University experiment, OSS-1 or VCAP (Vehicle Charging and Discharge) [22], will operate with pulses from 600 nanoseconds to 107 seconds and is designed specifically to study spacecraft charging of the orbiter. As such it will attempt to determine the charge accumulation on the orbiter and its resulting potential changes. The instruments designed to carry out these measurements are a charge and current measurement probe and a retarding potential analyzer Langmuir probe. Emphasis will be placed on the fast time response of the instruments. While the telemetry sampling rate of 60 bits per second limits this capability, peak detecting circuits can give an indication of rapid potential changes lasting only tens of nanoseconds.

Both of these experiments represent a significant step toward understanding the spacecraft charging and beam emission from the Shuttle. However, the peculiar electrical and geometric configuration of this vehicle will make it difficult to apply these data to other vehicles. While the electrical isolation of the French accelerator is a step in the right direction, the complexity of the evaluation of induced currents and fields will inhibit generalizing the data to smaller spacecraft. In order to predict charging properties, beam neutralization, and beam ejection limitations for future systems of unspecified geometry and electrical properties such experiments must be carried out using satellites having simple geometries, and controllable electrical properties.

The accelerator proposed by the University of Tokyo (Obyashi, principal investigator)[23] has a somewhat greater current dynamic range than the other two accelerators. It is planned to be reflown on a number of Shuttle flights. Its emission current capability will be upgraded to those shown in Table 5 as potential improvements at some time in the future. To permit full utilization of its capability it is planned to permit the University of Tokyo accelerator to be used by other investigators. For Spacelab 1, with a planned circular orbit at an altitude of 250 km and 57° inclination, the experiments shown in Table 6 are planned. SEPAC is an acronym for Space Experiments and Particle Accelerators, which describes the entire system, EBA (Electron Beam Accelerator), MPD (Magneto-Plasma Dynamic Arcjet) and NGP (Neutral Gas Plume).

The experiments to be carried out, as well as the low altitude orbit, are consistent with the auroral study interests of Professor Obayashi, the principal investigator. As can be seen from his remarks in Column 3 of Table 6, even for these purposes, the beam energy and power are not satisfactory and the planned improvements noted previously in Table 5 will not fully satisfy the needs for the low altitude, high latitude studies.

TABLE 6 SEPAC EXPERIMENTAL OBJECTIVES

FUNCTIONAL OBJECTIVE	DESCRIPTION	REMARKS
1. SEPAC System Checkout	Electrical checkout of SEPAC system.	Engineering test only.
2. EBA Firing Test (Level I)	Low-power firing test of EBA.	Preliminary information will be obtained on vehicle charging effects.
3. MPD Firing Test	Test firing of MPD and NGP to confirm operation of MPD Arcjet and Neutral Gas Plume.	
4. EBA Firing Test (Level II)	High-power firing test of EBA with simultaneous firings of MPD and NGP to investigate neutralization capabilities of MPD and NGP at high electron beam power.	In-beam and near-beam (RMS-mounted) diagnostics are needed for future experiments.
5. Electron Beam Experiment 1	Electron beam pulses (pulse widths of 10 and 100 ms) fired along magnetic field line at energies from 1 to 5 keV and beam currents from 100 to 300 mA. Will investigate vehicle charging and beam stability.	Plasma wave measurements on pallet may be contaminated by Shuttle EMI. Remote wave measurements are desired. Also, charging measurements should be made at several locations on Shuttle.

TABLE 6 SEPAC EXPERIMENTAL OBJECTIVES (cont'd)

FUNCTIONAL OBJECTIVE	DESCRIPTION	REMARKS
6. Electron Beam Experiment 2	Electron beam pulses (pulse width of 5 s) fired along magnetic field line at energies from 3 to 5 keV and beam currents from 100 to 300 mA. During each EBA pulse a short pulse (pulse width of 100 ms) of neutral gas (argon) is fired by the NGP to investigate the effects of the neutral gas plume on vehicle charging.	In-beam and near-beam (RMS-mounted) diagnostics are needed for future experiments.
7. Electron Beam Experiment 3	Same as Experiment 2 except with 1.3 ms pulses from the MPD Arcjet instead of the NGP pulses.	In-beam and near-beam (RMS-mounted) diagnostics are needed for future experiments.
8. Plasma Beam Propagation	Short (1 ms pulse width) 3 kJ pulses from the MDP Arcjet are fired along and perpendicular to the magnetic field line. Subsequent plasma motion is tracked optically.	Higher power desirable for ionospheric modification.
9. Artificial Aurora Excitation	Electron beam pulses (pulse width 0.5 s) are fired downward along the magnetic field line at energies of 3, 5, and 7.5 keV and beam currents of 400, 800, and 1600 mA. Artificial aurora observed by LLLTV and from ground.	Higher powers (up to 50 kW) required for spectral analysis.

TABLE 6 SEPAC EXPERIMENTAL OBJECTIVES (cont'd)

FUNCTIONAL OBJECTIVE	DESCRIPTION	REMARKS
10. Equatorial Chemistry	Joint experiment with LLLTV. Electron beam pulses (as in Functional Objective 9) are fired at 45° pitch angle with magnetic field line within 30° of the ram direction at the equator. Interaction volume viewed by LLLTV to study excitation of metastable states (such as 5577 A oxygen line).	Higher power desirable to excite stronger emissions at Orbiter altitude.
11. Electron Echo Experiment	Electron beam pulses (pulse width 50 ms) energy 7.5 keV, beam current 1600 mA) fired upward from South Atlantic Anomaly at 75° pitch angle. Beam mirrors in Northern Hemisphere and returns to strike atmosphere below and behind Shuttle, as observed by LLLTV. Used to measure field-line lengths and field-line-integrated E|B.	Higher energies (at least 20 keV) required to reduce bounce time and allow experiment to be conducted at higher altitudes where field lines are longer. Higher powers (up to 50 kW) required to allow operation at locations where conjugate point is not above the atmosphere. Direct detection of beam by multiple subsatellites required to increase temporal resolution and to allow daylight operation.

TABLE 6 SEPAC EXPERIMENTAL OBJECTIVES (cont'd.)

FUNCTIONAL OBJECTIVE	DESCRIPTION	REMARKS
12. E || B Experiment	Electron beam pulses (pulse width 0.1 s, energies of 1, 3, 5 and 7.5 keV, and beam currents of 80, 300, 500, and 1000 mA) fired up field line at various pitch angles. Reflection of beam by parallel potential drops (E || B) detected by LLLTV, which views atmosphere at expected beam return location.	Higher energies (at least 20 keV) required to distinguish beam electrons from auroral electrons and to prevent thermalization of beam inside potential drop region. Direct detection of beam by multiple subsatellites required to increase measurement resolution and to measure return spectrum, thereby distinguishing beam electrons from auroral electrons.

4. EXPERIMENTAL PLAN AND TECHNICAL OBJECTIVES

This section is a detailed outline of the overall experimental plan, which includes a series of 5 rocket and 6 shuttle flights. The rocket flights will serve as proof tests for the accelerators and the associated electron and ion guns and the neutralizer of the ion beam, as well as demonstrations of the operation and relevance of the diagnostic instruments, both space-borne and ground-based. Subsequent to the rocket flights, the equipment is to be used on a series of shuttle flights to elucidate the physics and engineering problems of the use of high-energy, high-current particle beams in space. Table 7 presents a listing of the Beam Energy Rocket Test (BERT) and Beam Energy Shuttle Test (BEST) flights and the fiscal years each is to be initiated and flown. Principal characteristics of the accelerators are also given. The dates indicated and used in the subsequent discussion assume program initation in FY82.

A series of five rocket tests are needed to test both the operation of the accelerators as they are developed and to obtain representative data samples in the portion of space to be studied. These rocket flights will be flown on Aries rockets which are sufficiently large to carry the proposed guns and accelerators (as well as the large amount of diagnostic equipment) which will be flown on the subsequent shuttle flights. The use of rockets to pre-test the operation of the accelerator systems and the diagnostic equipment will provide a savings in cost and provide for lead time in making minor changes in the overall experimental plan.

4.1 BERT I

The first rocket flight, BERT I, which is planned for flight in FY82, will contain a relatively low energy accelerator (~5 kV) to be used toward obtaining empirical results on particle beam physics. The objectives of this experiment will be to apply electron and ion beams on a rocket flight to:

a. study the effects that the ejection of charged particles have on the ambient atmospheric plasma and the host space vehicle.

b. characterize the scaling of spacecraft charging with particle species, energy, current and vehicle magnetic field orientation and altitude.

c. serve as a space test platform for an automatic charge control system.

TABLE 7 BEAM ENERGY TESTS

EXPERIMENT	YEAR INITIATED	YEAR FLOWN	SOURCE PARTICLES	ENERGY
BERT I	FY81	FY82	Electrons Ions	5 keV
BERT II	FY82	FY84	Electrons	300-500 keV
BERT III	FY83	FY86	Protons Neutrals	300-500 keV
BEST I	FY83	FY86	Ions Electrons Neutrals	50-100 keV
BERT IV	FY84	FY88	Ions Electrons Neutrals	~MeV range
BEST II	FY84	FY88	Electrons	50-100 keV
BERT V	FY85	FY89	Ions Electrons Neutrals	MeV range
BEST III	FY85	FY89	Ions Neutrals	50-100 keV
BEST IV	FY86	FY90	Ions Electrons	MeV range
BEST V	FY87	FY91	Neutrals	MeV range
BEST VI	FY88	FY92	Ions Neutrals	MeV range

d. provide direct experimental results on the engineering problems of operating moderate energy particle accelerator systems in space.

BERT I will employ several different beam systems to eject positive and negative charged particles of a wide dynamic range of current and energies. On-board instrumentation will be used to measure the transient and steady state vehicle potential, beam characteristics, the energy and density distribution of plasma surrounding the craft, and particle return currents. An automatic satellite active charge control system will periodically sense the vehicle potiential and return the vehicle ground to plasma potential.

BERT I will be a mid-latitude night flight, launched just before sunrise in order to obtain a wide range of ambient plasma densities. The payload apogee will be 250 km. The flight will be planned for a moonless period to allow optical measurements of the interaction of ejected and return currents with the rocket payload and its local environment. A complete charge ejection sequence will consist of bursts of negative charge and bursts of positive charge, each of a different combination of energy and current. This charge ejection sequence will be repeated continuously during ascent and descent. The Satellite Automatic Active Discharge System will be activated during flight.

The BERT I payload will be capable of measuring the parameters that characterize charge ejection and the effects of this process upon the host vehicle. The instruments required to perform these measurements include:

1. Charge Ejection Systems

   a. A keV Electron Source having a wide dynamic range of currents and energies.
   b. A keV Multiple Nozzle Ion Source having a wide dynamic range of currents, energies, and masses.

2. Vehicle Potential Measurements

   a. High-Impedance Boom-Mounted Spheres
   b. Intersegment Voltmeter
   c. Electrostatic Analyzer

3. Return Current Measurements

    a. Faraday Cups
    b. Mass Spectrometer

4. Ambient Plasma Measurement

    a. Electrostatic Analyzer
    b. Retarding Potential Analyzer

5. Optical Measurements

    a. TV Camera
    b. Photometers
    c. X-Ray Detectors
    d. U.V. Spectrometer

6. Satellite Automatic Active Discharge System

4.2 BERT II

The second rocket flight, BERT II, would be initiated in FY82 for flight in FY84. From the milestone schedule shown in Figure 1, we see that the experimental design specifications will result in procurement of the accelerator, electron gun, ion gun, and neutralizer chamber over 15 months following initiation of the proposed program. While this procurement and test is underway, the rocketborne diagnostic instruments and the total payload are to be designed, fabricated and tested for experimental integration. This will take place in the last quarter of the second year. After final test, calibration, and payload integration, BERT II is scheduled for flight in the third quarter of FY84. Data reduction and analysis of the results of the BERT II flight are scheduled for the following year, FY85.

The accelerator system to be used on the BERT II payload will consist of two accelerators. One of the accelerators will contain a tunable 50-100 kV high voltage system coupled to an electron gun capable of emitting about one ampere of current with pulses of a few seconds duration. The limiting factor in the operation of this system is the anode grid heating due to the intercepted current. The other accelerator will be a high current (10 amp), short pulse (5 μsec), 300 to 500 kV accelerator. The principal objectives of this flight are to test the electron accelerators in a space environment to ensure their proper operation before attempting to perform more elaborate shuttle experiments.

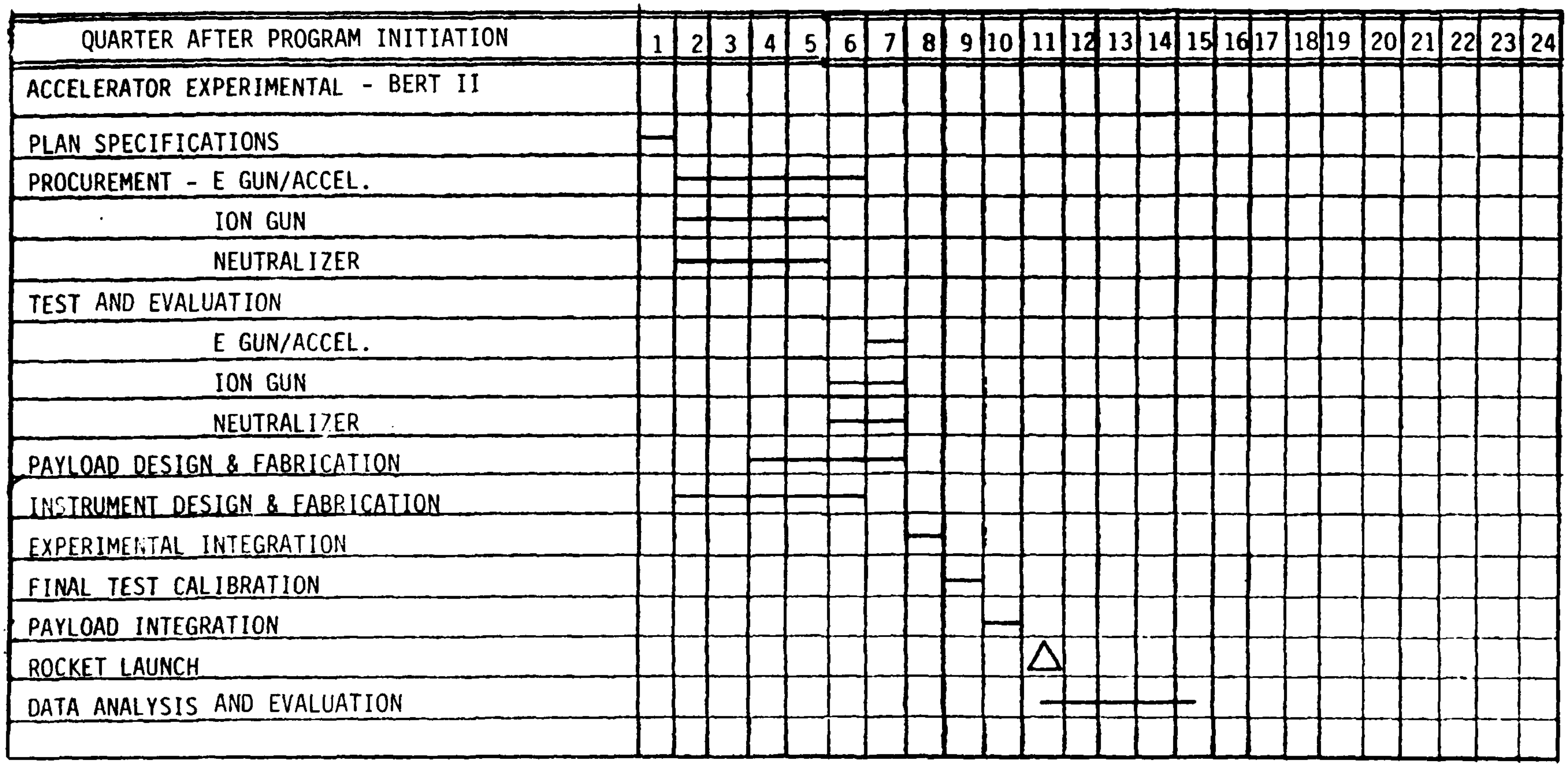

Figure 1: Milestone Chart for BERT II.

The diagnostic instrumentation to be carried as part of the BERT II payload and its purpose is the following:

a. Energetic particle detectors and analyzers - to determine particle flux, energy, and pitch angle distributions in the vicinity of the rocket.

b. Magnetometer - to determine magnetic field intensity, direction, and any perturbation of the field due to the beam.

c. Electric Field/Langmuir Probe - to measure the electric field and vehicle potential during pulse operation and after pulse turn-off.

d. Step Frequency Receiver - to detect plasma emissions in the 100 to 10^8 Hz range which are induced by the beams.

e. Retarding Potential Analyzer - to measure the concentration and energy of ions and electrons impinging on the vehicle.

f. Spin Scan Imaging System - to measure the time dependence and intensity, at selected wavelengths, of UV, visible, and IR emissions induced by the beam or the return current.

g. TV Beam Monitor - to ascertain the beam characteristics, such as length, width, and general radiation glow about the vehicle.

h. Electrometer - to give an additional measurement of vehicle potential.

i. Ion Mass Spectrometer - to provide ion concentrations near the vehicle, up to the mass of NO+, i.e. atomic weight equal to 30.

j. Arc Detector - to determermine rapid voltage changes indicative of fast charge-up and/or discharge.

k. X-ray Monitor - to determine the x-ray dose at the rocket and its energy spectrum.

l. Return Current Monitor - to measure the current intercepted by the accelerator grid and the return current to the skin of the vehicle.

Ground based instrumentation consists of telescoped LLTV monitors to observe the visible light emissions from the beam-air interactions and from the return current-air and vehicle interactions. RF Monitors to determine the emissions induced by beam-plasma interactions will also be used.

The two accelerators will be controlled so as to permit alternate firing throughout the flight. This will provide data on charge-up and beam behavior as a function of altitude, beam voltage (principally from 50 to 100 kV), and electron current. The current-pulse length combinations to be flown on BERT II should, apart from local plasma effects, permit substantial charge-up and/or, possibly, beam-plasma discharge effects to be observed. The maximum altitude permitted by the Aries capability and the BERT II payload weight is desired in order to obtain data on beam operation at densities more nearly comparable to those of the intended shuttle flights.

If the Aries is to be flown from the White Sands Missile Range, the flight trajectory required by Range Safety will preclude attempts at detecting the injected and trapped electrons on their subsequent bounces. A flight from the Poker Flat Rocket Range would permit (as demonstrated by the ECHO Tests) such beam-bounce interceptions.

4.3 BERT III

BERT III will be a reflight of the accelerators from BERT II, except that the electron gun will be replaced by a proton gun. In addition, a neutralizer will be employed to provide a mixed beam of energetic protons and neutral hydrogen atoms. The expected currents for the proton and neutral beams are three to four orders of magnitude smaller (i.e. milliamps) than those obtained in the electron beam configuration.

The diagnostic equipment will be the same as used in BERT II. However, because of the westward drift of the positively charged ions, interception of trapped ions can be attempted. We recall that in the ECHO IV experiment[10], the mirrored electron intensity was severely reduced from the anticipated levels, presumably due to pitch angle scattering in the magnetic equatorial regions. Since, for the same energy, the rigidity of ions is much larger than that of electrons, the effect of pitch angle scattering should not be as deleterious. Consequently we expect the return ion intensities to be large enough to be measurable if the return beam can be intercepted by the rocket trajectories.

4.4 BEST I

During the period FY83 to FY86, the first of six planned shuttle flights will be prepared and flown. This flight will be the first shuttle flight (BEST I) and will serve to develop the proper procedures for operating over sustained times. A milestone chart for this experiment is shown in Figure 2.

4.4.1 Experimental Objectives

The principal experimental objective of this flight will be to measure the interactions of energetic particles, electrons and ions, with the ambient neutral and plasma environment surrounding the shuttle as well as with the ambient magnetic field. On this first shuttle flight the BERT II and III lower energy accelerators are to be used. They are to be able to emit a high current (~1 amp) of electrons, a milliampere-range current of protons, or a comparable flux of neutral hydrogen atoms.

This experiment is designed to also test the theoretical predictions on the construction, coherence, and drift of a wedge of energetic charged particles in the geomagnetic field. At different times during the flight, the charged particle sources will be used to form wedges of electrons and protons. Since these wedges may result in the immersion of a satellite in a high flux of energetic particles, it is important to know the characteristics of the wedge at these energies, at the higher altitudes of injection permitted by the shuttle orbits, and at the equatorial geomagnetic regions traversed. That is, we would like to know what the drift velocities are, over how long a time the wedges remain coherent, and the degree of coherence for electrons and ion wedges, or that is, the degradation of the particle energies and their spread in pitch angle distribution.

The loss of particles from the wedges will be different for the ions and electrons. The pitch angle scattering at low magnetic latitudes of the ECHO IV electrons, as inferred by Winckler[10], may or may not occur at the lower L-shells. As discussed above, this effect may or may not occur at all for heavy particles, such as the protons. The ranges for the protons and electrons are quite different for the same kinetic energy and the plasma-wave interactions should also be mass (i.e. momentum) dependent.

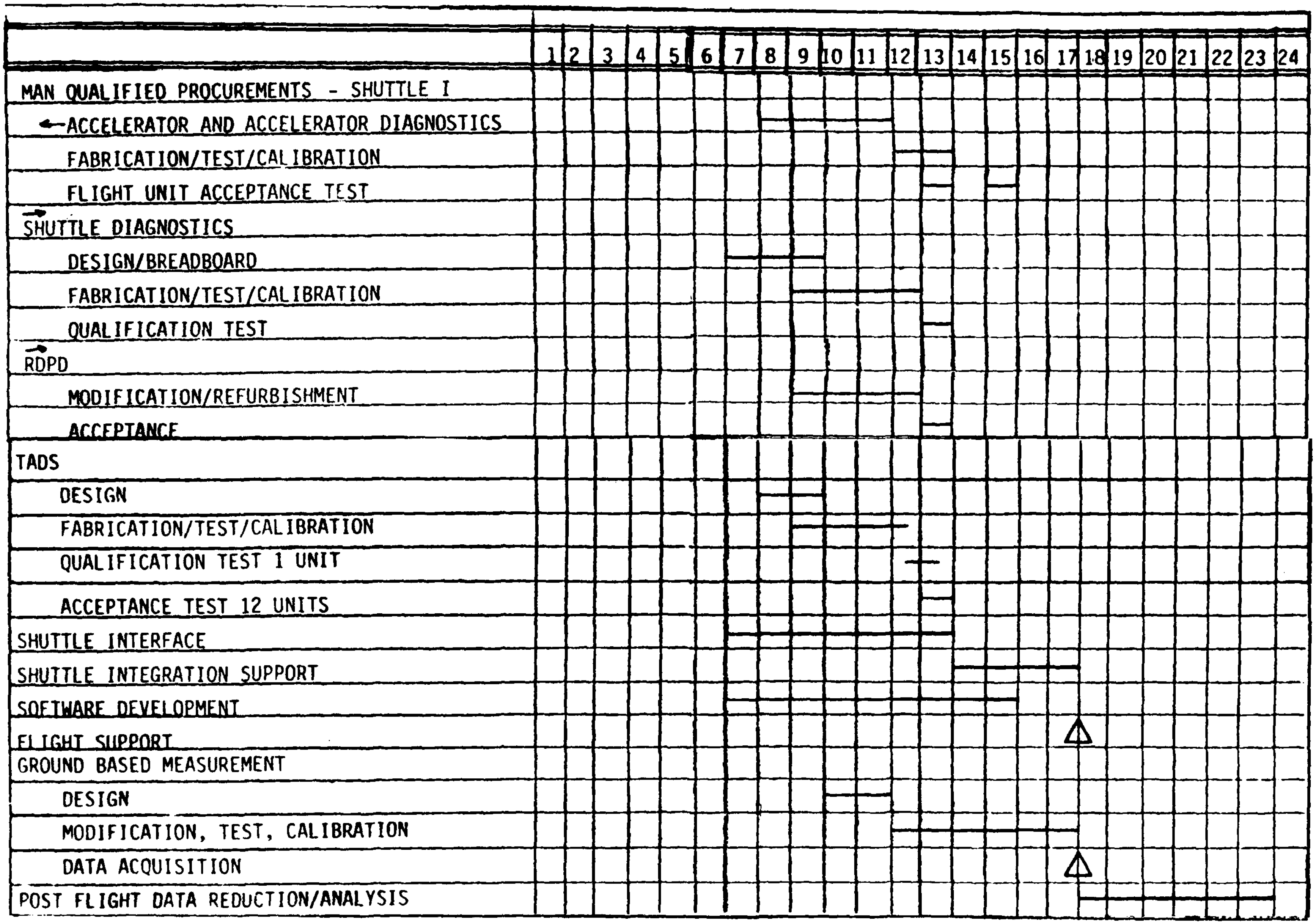

Figure 2: Milestone Chart for BEST I.

The neutral beam of hydrogen atoms will probably be most easily produced by charge exchange of the ion beam through an N_2 gas flow. Hence, from this exchange region, we will have a flow of energetic neutral hydrogen atoms, a comparable flow of protons which did not undergo charge exchange in the neutralizer, and a cloud of low energy, ionized nitrogen molecules drifting from the neutralizer under the influence of the geomagnetic field, the accelerator leakage fields, and the shuttle charge-up fields.

As our final objective, we wish to determine the x-ray, UV, visible, near infrared, and RF emissions generated by the interaction of the emitted beams with the surrounding atmosphere and with the ambient plasma and that produced by beam energy deposition. The experiment is summarized in Figure 3.

4.4.2 Experimental Methods

To ensure a high degree of trapping, injection should take place near the geomagnetic equator. To determine the effects of pitch angle scattering and the effects of atmospheric scattering, careful monitoring of the pitch angle distribution and the energy flux and spectrum must be made at a number of points from the injection region. The use of the recoverable plasma diagnostic package (RPDP) and less costly throw-away detectors (TADs) can provide these data.

To perform this part of the experiment, the RPDP is ejected before the wedge is constructed and the shuttle maneuvered so that the RPDP trajectory intersects with the drifting wedge. To provide a proper set of conditions, a choice must be made of the details of the inclined orbit of the shuttle, the degree to which it can be maneuvered away from the RPDP, the relative orientation of the geomagnetic field and the orbit, and the intersections of the orbit of the RPDP with the invariant shells on which the electrons drift. For example, if electrons are injected while the shuttle is crossing the magnetic field lines at the latitudinal extreme of its orbit, then a radially thin wedge is formed which drifts eastward behind the shuttle. If the orbit and injection regions are properly chosen, the RPDP satellite will be intersected by the wedge at least once.

- OBJECTIVES

  DETERMINE INTERACTION OF ENERGETIC ELECTRONS AND IONS WITH MAGNETIC FIELD, AMBIENT NEUTRALS AND PLASMA

  DETERMINE EMISSIONS (VIS, UV, IR, RF, X-RAY)

  EJECT AND MEASURE NEUTRAL HYDROGEN BEAM

  CONSTRUCT ENERGETIC ELECTRON AND POSITIVE ION WEDGES

  DETERMINE LOSS OF ENERGETIC ELECTRON AND POSITIVE ION WEDGES

- METHOD

  DIALABLE 50-100 KV ACCELERATOR WITH ELECTRON SOURCE, ION SOURCE, AND BEAM NEUTRALIZATION SYSTEMS

  INJECT IN MAGNETIC EQUATORIAL REGION

  ON-BOARD AND EJECTABLE DIAGNOSTIC PACKAGES

- RESULTS

  VERIFY PARTICLE PROPAGATION THEORY IN MAGNETOSPHERE
  ESTABLISH BEAM-PLASMA INTERACTIONS
  ESTABLISH NEUTRAL BEAM BEHAVIOR AND INTERACTIONS
  ESTABLISH WEDGE COHERENCE, LOSS AND INTERACTIONS

Figure 3: Summary of BEST I Experiment.

From the electron energy and intensity the wedge's passing can be discriminated. To provide a wedge which survives for the longest period, injection at the South Atlantic anomaly will ensure the highest mirroring altitudes around the earth and in both its hemispheres. Similar considerations for release and trajectory pertain to the TADs, with the added freedom that the TADs are not recovered.

Referring to Table 7, the BEST I experiment would be initiated in FY83 and flown in FY86. Figure 2 gives the details of procurement, test, calibration and integration schedules necessary to permit the targeted flight date to be achieved. Figure 4 lists the instruments needed on each experimental platform (the recoverable package - RPDP, the throw-away packages - the TADs, the shuttle itself, and the ground station) along with the intended measurements.

4.4.3 Desired Results

The desired results from BEST I are:

a. to verify the theory of particle motion used to describe the mirroring and drift of both the electrons and ions;

b. to determine the effects of pitch-angle scattering in the equatorial regions;

c. to establish the wedge coherence, particle interactions and particle loss from the wedge;

d. to determine the beam-plasma interactions, if they exist; and

e. to detect the neutral beam behavior and its interactions and emissions.

Data will be taken, insofar as permitted by the trajectory of the shuttle flight, over the largest possible range of altitudes (i.e. density at injection), ambient electron concentrations (i.e. day or night), L-shells of injection, magnetic activities, and pitch angle distributions. For purposes of wedge construction the lower energy (50-100 kV) accelerators will be used due to the longer pulse lengths (~ few seconds). These pulse lengths permit a larger wedges to be built and, thus, increase the probability of interception by the RPDP and TADs.

- EJECTABLE PACKAGE (RECOVERABLE): MODIFIED RPDP
  - Energetic Particle Detectors And Analyzers - Flux, Energy, And Pitch Angles
  - Magnetometer - Mag. Field Intensity, Direction, And Beam Perturbation Of Field
  - Electric Field/Langmuir Probe - Electric Field, Vehicle Potential
  - Step Frequency Receiver - Plasma Emissions - 100 Hz To 100 MHz
  - Retarding Potential Analyzer - No. Density, Energy Of Ions And Electrons
  - Spin Scan Imaging System - Visible, UV, IR at Selected Wavelengths
  - Beam Monitor TV - Beam Characteristics, Length, Time, Glow About Vehicle
  - Electrometer - Vehicle Potential
  - Ion Mass Spectrometer - Ion Concentration And Spectrum To Fe^+
- SHUTTLE-BORNE
  - Modified RPDP Components
  - Arc Detector - Rapid Voltage Changes
  - X-Ray Monitor - X-Ray Dosage And Spectrum
  - Return Current Monitor - Return Current
- TADS (NON-RECOVERABLE)
  - Magnetometer - Magnetic Field Intensity And Direction
  - Energetic Particle Detectors - Wedge Particle Flux and Pitch Angle Distribution
  - Particle Energy Analyzer - Wedge Particle Flux and Energy Distribution
- GROUND PACKAGE
  - Filtered LLTV - Energy Deposition and Beam Behavior
  - Frequency Monitor (Existing Facilities) - R.F. Emissions

Figure 4: BEST I Diagnostics.

4.5 BERT IV

This rocket flight has as its objective the test of the spaceborne behavior of an accelerator in the megavolt regime. Because of the high voltage breakdown problems that arise as one attempts to operate unsealed systems in a medium that contains electrons and ions, a development program will be required to ensure a reliable high voltage, high current pulse accelerator for shuttle use. This development program should be initiated in FY84 to allow BERT IV to fly in FY 88. As in BERT II, this experiment should be restricted to electron beam measurements in order to permit the study of very high voltage charge-up and the interaction of megavolt electrons with the surrounding plasma.

4.6 BEST II

During the period from FY84 to FY88, BEST II is to be prepared and flown. The lower energy accelerator by this time will have undergone two rocket test flights (BERT II and BERT III). The BEST II flight is to be used employing the electron gun only. To permit electrical conditions at the emitting body to be controlled in a manner that will permit tractable analyses of phenomena such as charge-up, differential charge-up, break-down, and neutralization, the accelerator is to be integrated into a specially designed subsatellite that can be ejected from the shuttle and recovered after the experiment has been completed. The overall objectives, methods and desired results are summarized in Figure 5.

4.6.1 Experimental Objectives

The primary objective of this shuttle experiment is to understand the physics of high voltage fast-time charge-up of a satellite in space from which a high current beam of charged particles is emitted. In principle the charge-up time can be very short; therefore, techniques to monitor potential variations must be able to measure microsecond rise times. A subsidiary objective is to determine the behavior and characteristics of the electron beam that is emitted from a satellite that has been driven to a high potential but that has not reached beam potential. The whole phenomenon of beam-plasma discharge that has recently been the subject of a number of laboratory experiments is yet to be systematically explored in space, where the role of the collector plate and the collector-emitter

- OBJECTIVES
  - DETERMINE HIGH VOLTAGE, HIGH CURRENT, FAST-TIME CHARGE-UP (ELECTRONS)
  - DETERMINE EJECTED BEAM BEHAVIOR FROM NON-NEUTRALIZED VEHICLE
  - DETERMINE EFFECTS OF LOCAL PLASMA ON CHARGE-UP
  - DETERMINE AMBIENT DENSITY EFFECTS ON CHARGE-UP
  - DETERMINE ACTIVE AND PASSIVE METHODS OF SPACE-CRAFT NEUTRALIZATION
- METHODS
  - USE EXPERIMENT 1 ACCELERATOR IN NON-CONDUCTING SUB-SATELLITE
  - USE VARIABLE AREA, SIMPLIFIED GEOMETRY, CONDUCTING SURFACE TO CONTROL NEUTRALIZATION
  - USE VARIABLE CURRENTS TO STUDY LOCAL PLASMA EFFECTS
  - VARY EXPERIMENT ALTITUDE TO CHANGE AMBIENT DENSITY
  - VARY CURRENT BUILD-UP TO STUDY CHARGE-UP TIME EFFECTS
  - USE CONDUCTING SAIL AND NEUTRAL GAS RELEASE
  - USE IONIZATION SOURCE WITH GAS RELEASE TO PRODUCE INCREASED LOCAL PLASMA DENSITY
  - USE POSITIVE ION GUN TO NEUTRALIZE
- RESULTS
  - OBTAIN EXTREME CHARGE-UP BEHAVIOR OF EJECTED BEAM
  - OBSERVE SECONDARY-ELECTRON PLASMA BEHAVIOR
  - OBSERVE ANY INDUCED PLASMA WAVES OR BEAM PLASMA DISCHARGE
  - OBSERVE SOLAR DISCHARGE EFFECTS
  - DEVELOP GUIDELINE FOR SPACE-CRAFT NEUTRALIZATION

Figure 5: Summary of BEST II Experiment.

distance is still undefined. In this same vein, the ambient neutral density and the plasma in the immediate vicinity of the satellite play roles both in the minor and extreme charge-up regime that are poorly understood in terms of neutralization, production of plasma and/or beam instabilities, and generation of RF and optical/IR emissions. A final objective of BEST II is to study active and passive methods of spacecraft neutralization and to determine the efficacy of various methods as a function of ambient density, beam voltage and current, etc.

4.6.2 Experimental Methods

As previously noted, the flight-tested accelerator and certain of the diagnostic instruments used earlier are to be used. The ejectable subsatellite that is to carry this accelerator system should enclose the accelerator and use a variable collector area of simplified geometry to allow systematic control of charge-up and neutralization. This subsatellite could use, for example, an insulating spherical shell completely enclosing the accelerator with a flat plate conductor collector attached by an umbilical cord. The accelerator should be isolated from the shell to withstand the intended high voltage (50-100 kV). Under these conditions one should be able to ensure very high voltage charge-up. To examine the charge-up, the beam current build-up should be varied sufficiently slowly and controlled in amplitude to permit the time behavior to be resolved. Similarly, varying the current and the ambient density by the choice of experiment altitude and/or orbit permits the effects of the locally induced plasma on the electrical behavior of the subsatellite to be determined. Methods of neutralization to be explored include the use of a conducting sail, the release of a gas cloud to allow the beam to increase the local plasma density, the use of a cloud and low energy ionization source to increase the local plasma, and the use of a positive ion or plasma gun.

It is planned to use both active and passive techniques. The most obvious passive technique will have been investigated in BEST II in studying charge-up. The advantage of a sail is that it is passive and non-electrical. The disadvantages are the obvious penalties of weight, cost, mechanical complexity, and the eventual limitations for high current systems; however, in conjunction with other techniques it may prove to be useful. The most obvious active technique is to use an ion gun which ejects comparable amounts of positive charge to keep the spacecraft potential always near zero. The advantages are the ability to synchronize the ion and electron gun systems and to be able to view the test results in the light of the use of an electron gun to neutralize large positive current systems or charge-contaminated neutral beams. The disadvantages are the weight and ion source problems encountered in very high currents and voltages. Two other potential techniques depend upon the emission of EUV or XUV or low energy electrons or ions required to increase the local ionization by orders of magnitude to provide an available nearby source of neutralizing charge. These techniques should operate most efficiently at the lower altitudes where the density is higher and the particle range or photon mean free path is shorter; thus, they may be inappropriate for some shuttle altitudes. A possible solution is to design the system to allow the spacecraft to charge-up not to the full beam value of 100 kilovolts, for example, but to 1 to 10 kilovolts in order to attract neutralizing charge from the surrounding medium.

4.6.3 Desired Results

Charge-up of a satellite to voltages higher than a few kilovolts has not been observed to date. As the voltages attained increase, the discharge effects and paths will become more esoteric and produce effects not easily predicted. The behavior of the surrounding plasma and the secondary electron cloud under these conditions will become extreme and may lead to behavior akin to that observed in laboratory chambers (for example, the notorious beam-plasma discharge). Furthermore, instabilities in such conditions may induce severe oscillations of various sorts in the plasma and produce waves detectable either at a distance or near by. The effects of altitude, solar illumination, beam voltage, and beam current on these phenomena are desired. Guidelines for spacecraft neutralization will be developed for simplified conditions. These guidelines will allow extrapolation to more complex situations and hopefully to much higher voltage and current accelerators.

4.7 BERT V

This rocket experiment has as its main objective to test fly for the first time a relatively high current, megavolt pulsed electron accelerator. The development of this gun-accelerator system is to start in FY85 for flight in FY89 (see Table 7). Again, to simplify the flight requirements, BERT V will be concerned only with the emission of an electron beam although during accelerator development, a high current ion gun and a neutralizer system will be developed and tested in the laboratory for flight later. The diagnostic equipment will have to be upgraded to detect the higher energy particles. Some of the techniques, for neutralization, developed earlier, will be employed to permit emission of a currents as high as possible during this test flight. No particular attempt will be made to monitor any wedge of energetic electrons produced; however, measurements will be made of beam induced RF and optical/IR emissions as an aid in beam detection and diagnostic studies.

4.8 BEST III

This experiment is designed to repeat many of the measurements of BEST II, but with the accelerator operated in the positive ion and neutral beam modes. The overall objectives, experimental methods and desired results are summarized in Figure 6.

4.8.1 Experimental Objectives

Charge-up to high negative voltages (50 - 100 kV) may be less difficult to achieve using ions due to the low mobility of the neutralizing heavy ions of the surrounding plasma. However, the effects on the initiation of plasma oscillations and such phenomèna as beam-plasma discharge may be quite different when the sign of the high voltage charge-up is such that electrons are repelled rather than attracted in a geometrically converging situation and may give rise to avalanche type of collisional processes. Given such a negative voltage build-up, we wish to determine the effects on the beam ejected from the vehicle, as well as the effects of variation in the ambient density with altitude and the concentration of artificially increased local density. The so-called neutral beam, of course, retains an appreciable fraction of energetic ions, as well as the swarm of low-energy charge-exchanged molecules. It is useful for future extrapolations to determine the percentage of the energetic beam that is neutralized. This shall be done as a function of the critical parameters - ambient density, ambient ionization, and particle beam energy and initial current, for example. Active methods of neutralization of spacecraft charge-up need to be studied here. The most obvious approaches are to use a low energy electron gun that emits a sufficient current (or causes enough additional

- OBJECTIVES

  DETERMINE HIGH VOLTAGE, HIGH CURRENT, FAST-TIME CHARGE-UP (IONS AND NEUTRALS (?))
  DETERMINE BEAM BEHAVIOR EJECTED FROM NON-NEUTRALIZED VEHICLE
  DETERMINE EFFECTS OF LOCAL PLASMA ON CHARGE-UP
  DETERMINE AMBIENT DENSITY EFFECTS ON CHARGE-UP
  DETERMINE CHARGE-UP EFFECTS WHEN USING NEUTRAL BEAM
  DETERMINE ACTIVE METHODS OF NEUTRALIZATION

- METHODS

  USE EXPERIMENT 2 ACCELERATOR AND SUB-SATELLITE
  USE LOW VOLTAGE E-GUN DISCHARGE SYSTEM
  USE VARIABLE CURRENT TO STUDY LOCAL PLASMA EFFECTS

- RESULTS

  OBTAIN EXTREME CHARGE-UP BEHAVIOR OF EJECTED BEAM
  OBSERVE ANY INDUCED PLASMA WAVES OR BEAM PLASMA DISCHARGE
  OBSERVE SOLAR DISCHARGE EFFECTS
  DEVELOP GUIDELINES FOR SPACE-CRAFT NEUTRALIZATION

Figure 6: Summary of BEST III Experiment

secondary ionization to be produced in the immediate vicinity of the spacecraft) to neutralize the emitted positively charge ions or to use an intense plasma gun.

4.8.2 Experimental Methods

Again the accelerator from BEST II is to be flown in the subsatellite. Because of the change in the guns employed and the requirement for the neutralization system to produce the energetic neutral beam, some reconfiguration will be needed. Changes in the diagnostic equipment may have to be made to allow a more efficient detection of the energetic ions and/or neutrals. The low-voltage E-gun mentioned above will be required as well as a gas flask and control for release of gas to increase the local density. Variable currents and voltages on the accelerator will be used to help in understanding charge-up, neutralization, and initiation of any instabilities in the beam plasma.

4.8.3 Desired Results

From this experiment we wish to obtain high negative voltage charge-up effects, the effects of discharge due to solar illumination, and any induced plasma waves or beam plasma discharge effects. We wish also to develop guidelines for high negative voltage spacecraft neutralization.

4.9 BEST IV

The very high energy accelerator flown on BERT IV in the electron beam configuration and on BERT V in the ion and neutral beam configurations should be tested sufficiently for use on this flight scheduled for FY90.

4.9.1 Objectives

As listed in Figure 7, the objectives in this experiment are first, to determine the very high voltage charge-up effects using the subsatellite approach, second, to extrapolate the neutralization techniques developed earlier and to study their efficacy under these higher voltage conditions, and finally, as a subsidiary objective to determine high energy electron wedge phenomena such as field saturation effects when the trapped particle kinetic energy density becomes comparable with the field magnetic field density.

4.9.2 Experimental Methods

A very high energy (multi-megavolt) accelerator probably of the Marx or Van de Graaff types will be used to produce high currents of electrons and ions. Previously studied neutralization methods will be recon-

- OBJECTIVES

  DETERMINE VERY HIGH VOLTAGE EFFECTS ON BEAM EJECTION
  DETERMINE HIGH ENERGY PARTICLE WEDGE BEHAVIOR

- METHODS

  USE MARX OR VAN DE GRAAFF ACCELERATOR TO PRODUCE MEV ELECTRONS AND IONS
  USE PREVIOUSLY DEVELOPED TECHNIQUES TO STUDY CHARGE-UP AND NEUTRALIZATION
  STUDY FIELD SATURATION EFFECTS FOR IONS AND ELECTRONS

- RESULTS

  ESTABLISH VERY HIGH VOLTAGE CHARGE-UP EFFECTS
  VALIDATE GUIDELINES DERIVED EARLIER
  ESTABLISH ELECTRON/ION BEAM EJECTION DIFFERENCES
  ESTABLISH PARTICLE BEHAVIOR UNDER TRAPPING BREAKDOWN CONDITIONS

Figure 7: Summary of BEST IV Experiment

figured where necessary to provide stand-off for the higher voltages and the RPDP and TADs will again be used to monitor the wedge dynamics. Ultimately the desire in space applications for delivery of large amounts of power and energy will require the use of Bev particles. To determine the use of effects peculiar to these higher energies, it is planned to produce electron beams of energies significantly higher than any previously ejected in space. From the point of view of atmospheric scattering a wedge produced by particles of high energy would survive longer than those created in BEST I. However, other effects may enter into the beam strength limit as well as wedge survivability. These are unsupressable high voltages on the spacecraft which limit emissiability, self-field effects and the inability of magnetic field to contain the desired particle energy densities.

4.9.3 Desired Results

The experiment results will provide data on very high negative voltage charge-up effects and either validate or correct the guidelines derived from the earlier lower voltage measurements. During this experiment very high voltage electron/ion beam ejection differences will be established and the particle behavior under trapping and, hopefully trapping breakdown conditions will be explored.

4.10 BEST V

4.10.1 Objectives

The gas target techniques for charge exchange of an energetic beam is reasonably effective at the lower energies (50-100 kV); however, as the particle energy increases the charge exchange cross section falls steeply. Hence at higher energies, other techniques must be explored in order to provide reasonable "currents" of neutral beams. Further these techniques will by their nature probably never produce a totally neutral beam, therefore, the behavior of the charged component must be determined. The interaction effects of the neutral beam - target interaction - on the remaining portion of the beam pulse (for example, the ultraviolet/visible emission from the target region and the subsequent ionization by this radiation on the remaining neutral beam particles. See Figure 8.

4.10.2 Experimental Method

The BEST IV accelerator will be used in conjunction with one or more neutralizer designs. TADs will be used with special instrumentation to determine the neutral beam flux and beam - subsatellite interactions. Again these interactions must be determined as a function of ambient density, beam energy, and current.

OBJECTIVES

Study Neutral Beam Ejection

Study Behavior of Neutral Beam in Space

METHOD

Use Experiment 4 Accelerator in Conjuntion With Neutralizer

RESULTS

Determine Effects Of Charged Component On Neutral Beam System

Determine Beam-Plasma Interactions

Determine Beam Propagation

Determine Behavior Ionized Beam Produced At Sub-Satellite

Figure 8: Summary of BEST V Equipment

4.10.3 Desired Results

The effects of the charged component of the "neutral" beam on the ejection of this beam must be determined. The beam propagation must be followed to reasonable distances and its coherence ascertained. The effects of the beam in inducing beam-plasma or beam - wave interactions must be examined, and, finally, the behavior of the ionized beam produced at the subsatellite by the impinging neutrals must be detailed for future extrapolation.

4.11 BEST VI

Ejection of neutral beams in space will always be accompanied, for the foreseeable future, by a charged component. For extremely high energy particles (~ 100's Mev), the negative charge stripping procedure will result probably in a negative ion beam component remaining (as well as a positive beam). Hence, the satellite will charge positively and be neutralized from the outside by an influx of electrons from the surroundings or by emission of positive ions from the spacecraft as shown in Figure 9.

4.11.1 Objectives

In this experiment we wish to work with a negatively charged ion beam and neutralize it by a stripping method. The behavior or the system under positive charge-up is to be studied. Here much of the research performed with the emitted energetic electron beams can be used.

4.11.2 Experimental Method

Techniques developed in BEST II and BEST IV will be used and expanded to assist in the neutralization of the spacecraft. It is recognized that if a neutral beam weapon were to be developed, the charged component could cause undesirable collateral damage, both to the emitting vehicle and to chance objects in its path. Thus total charge component suppression will be a desirable objective. Realizing that, in the finite volume and weight aboard a space vehicle, this is highly unlikely to be achieved, new methods need to be developed to get rid of such effects. Ideally the remaining charge component would reenter the charge exchanger for repeated traversal. This may be achievable in a torroidal chamber with associated magnetic field which would permit neutral component exit after half-traversal and continue charge component around the race track. Other possibilities might be an isolated high voltage section at exit slot or deliberate charge beam return to the skin of vehicle.

OBJECTIVE

Study Behavior Of Charged Component Of Neutral Beam

METHOD

Use Results From Earlier Experiments On Very High Voltage Charge-Up To Encompass Accelerator And Neutralizer System

RESULTS

Validate Techniques To Eject A Charge-Free, High-Energy, Neutral Beam

Figure 9: Summary of BEST VI Experiment

4.11.3 Desired Results

Techniques for discharge will be validated in an attempt to provide a charge-free high energy neutral beam undisturbed by vehicle charge-up.

5. PROGRAM AND COST ESTIMATES

The experimental plan to investigate systematically the physics of particle beam ejection in and transmission through near earth space was developed in Section 4. A schedule was developed there for five rocket and six satellite flights utilizing particle sources and accelerators increasing in energy from the low keVs to MeVs. It was recognized that, even though off-the-shelf equipment for the required experiment does not exist, the state of the art is such that they can be developed by the time required.

The program timetable permits an orderly progression to higher energy accelerators. This timing results in the gradual extension of our state of knowledge and hence the ability to forecast more accurately the diagnostic and experimental changes required and also the orderly design and development of the higher energy accelerators. Table 8 shows the rockets and satellites for which the various accelerators are required.

We have carried out cost analyses for the various rocket and satellite flights. Recognizing, however, that for projected experiments at the edge of the state of the art, such analyses are only estimates. We feel, however, that the total program costs projected are good to ± 30%, going from an accuracy of ± 15% of the early experiments to ± 50% of the later ones. All cost figures are in FY80 dollars.

BERT I, which is already funded and partially procured, has not been included in the cost projection. Tables 9, 10, and 11 indicate the costs of BERT II, BEST I, and BEST II, respectively.

The cost estimates given assume that the rocket flights will be conducted from a domestic launch site, most likely White Sands but conceivably Poker Flat or Wallops Island, and that Aries type rockets will be used. The cost estimates for these rocket flights include integration costs.

For the satellite flights, it is assumed that the Shuttle will provide the basic transporation and that the Space Test Program (STP) will provide support for this service. Cost estimates do not include cost for the Shuttle vehicles or integration into the same. Instrumentation would be delivered to the launch site assembled, that is, integrated, to Level V (See Appendix B).

TABLE 8 BERT ROCKET FLIGHTS AND BEST SATELLITE FLIGHTS OF VARIOUS ACCELERATOR SYSTEMS

PARTICLE \ ENERGY	5 keV	50/100 keV	300/500 keV	MeV
Electrons	BERT-I	BERT-II BERT-III BEST-I BEST-II	BERT-II BERT-III	BERT-IV BERT-V BEST-IV
Ion	BERT-I	BERT-II BERT-III BEST-I BEST-III	BERT-II BERT-III	BERT-IV BERT-V BEST-IV BEST-VI
Neutral		BERT-II BERT-III BEST-I BEST-III	BERT-II BERT-III	BERT-IV BERT-V BEST-V BEST-VI

TABLE 9 ESTIMATED COSTS - BERT II (Amounts in Thousands of FY80 $)

Program Management/Scientific Direction/Quality Assurance	350
Accelerator I - (50/100 keV)	2,000
Accelerator II - (300/500 keV)	3,000
Diagnostics	750
Ground Based Measurements	200
Data Analysis	600
Integration/Rocket System	1,200
	8,100

TABLE 10 ESTIMATED COSTS - BEST I (Amounts in Thousands of FY80 $)

Program Management/Scientific Direction/Quality Assurance	700
Accelerator & Accelerator Diagnostics (Electron, Ion, Neutral)	6,000
Shuttle Diagnostics	1,000
Refurbish/Modify RDPD	2,000
TAD (12 Subsatellites)	1,800
Shuttle/Interface/Integration Support	400
Ground Base Measurements (Existing Facility Mod/Test/Cal/Data Acquisition)	200
Software (Exp Plan/Data Red/Data Acquisition)	300
Flight Support	100
Post Flight Data Reduction/Analysis	1,000
	13,500

TABLE 11 ESTIMATED COSTS - BEST II (Amounts in Thousands of FY80 $)

Program Management/Scientific Direction/Quality Assurance	500
Accelerator and Accelerator Diagnostics (Partial Refurbishment)	1,800
Accelerator Subsatellite (Structure, ACS Command TM, Data Processing, etc.)	2,000
Shuttle Diagnostics (Refurbishment)	250
Refurbish/Modify RDPD	1,500
TADS (12 Subsatellites)	1,200
Ground Based Measurements (Existing Facility Mod/Test/Data Red/Data Acquisition)	200
Software (Exp Plan/Data Red/Data Acquisition)	200
Flight Support	50
Post Flight Data Reduction and Analysis	1,000
	8,700

Table 12 summarizes the cost of the entire program both by flight and year. Times of rocket and satellite launches are also indicated.

It should be remembered that all costs were based on refurbishment and maximum reuse of equipment previously developed and that, therefore, the total program costs are considerably below the costs which would arise if each experimental flight were developed separately.

Table 12 Program Cost in Millions of FY80 Dollars by Flight and Year (BERT I, which is already programmed is not included in this table)

Program/Year	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	Program Total
BERT II	2.6	2.8	*2.1	0.3	0.3								8.1
BERT III				2.0	*2.0	0.3	0.3						4.6
BERT IV		.25	1.15	3.0	3.0	*2.0	0.3	0.3					10.0
BERT V						2.0	*2.0	0.3	0.3				4.6
BEST I	0.2	4.0	3.3	3.0	*2.0	0.5	0.5						13.5
BEST II			0.5	2.0	2.0	2.0	*1.2	0.5	0.5				8.7
BEST III				0.5	2.0	2.0	*3.2	0.5	0.5				8.7
BEST IV					0.5	2.0	2.0	*3.2	0.5	0.5			8.7
BEST V						0.5	2.0	2.0	*3.2	0.5	0.5		8.7
BEST VI							0.5	2.0	2.0	*3.2	0.5	0.5	8.7
Year Total	2.8	7.05	7.05	10.8	11.8	11.3	12.0	8.8	7.0	4.2	1.0	0.5	84.3

*Launch Time

REFERENCES

1 Hess, W.N., M.C. Trichel, T.N. Davis, W.C. Beggs, G.E. Kraft, E. Stassinopoulos, and E.J.R. Maier, "Artificial Aurora Experiment: Experiment and Principal Results", J. Geophys. Res., 76, 6067, (1971)

2 Winckler, J.R., "The Application of Artifical Electron Beams to Magnetospheric Research", Rev. Geophys. Space Phys., 18, 659, (1980)

3 Carpenter, J.W., L. Katz, H.J.P. Smith, and C.H. Humphrey, "Uses of Charged Beams", VI-337, AFGL-TR-77-0190, October, 1976

4 H.A. Cohen, T. Aggson, A.L. Chesley, M.S. Gussenhoven, D.A. Hardy, I. Michael, R.C. Olsen, E. Whipple and S.T. Lai, "A Direct Comparison of Three Techniques of Discharging Satellites", Proc. USAF/NASA Spacecraft Charging Technology Conference III, 12-14 Nov. 1980 (in press)

5 Winckler, J.R., R.L. Arnoldy, and R.A. Hendrickson, "ECHO II: A Study of Electron Beams Injected Into the High Latitude Ionsophere from a Large Sounding Rocket", J. Geophys. Res., 80, 2083 (1975)

6 Maehlum, B.N., B. Grandal, T.A. Jacobsen, and J. Traim, "Preliminary Analysis of the Electron Observations of the Polar 5 Pulses", Planet Space Sci. 28, 279 (1980)

7 Bernstein, W.H., L. Leinbach, P.J. Kellogg, S.J. Monson, and T. Hallinan, "Further Laboratory Measurements of Beam-Plasma Discharge", J. Geophys. Res., 84 7271 (1979)

8 Cartwright, D.G., S.J. Monson, and P.J. Kellogg, "Heating of the Ambient Ionsophere by an Artifically Injected Electron Beam", J. Geophys. Res., 83, 16 (1978)

9 Cohen, H.A., C. Sherman and E.G. Mullen, "Spacecraft Charging Due to Positive Ion Emission: An Experimental Study", Geophys. Res. Letts. 6, 515 (1979)

10 Hallinan, T.J., H.C. Stenback-Nielsen, and J.R. Winckler, "The ECHO IV Electron Beam Experiment: Television Observation of Artificial Electron Streaks Indicating Strong Beam Interaction in the High Latitude Magnetosphere", J. Geophys. Res., 83, 3263 (1978)

11 Hendrickson, R.A., R.L. Arnoldy and J.R. Winckler, "ECHO III - The Study of Electric and Magnetic Fields With Conjugate Echoes from Artificial Electron Beams Injected Into the Auroral Zone Ionosphere", Geophys. Res. Lett. 3, 409 (1976)

12 Cambou F. et al., Annales de Geophysique "Special Issue on the Results of the Active French-Soviet ARAKS Experiments", 36, No. 3, (1980)

13 Shepherd, O., J.W. Carpenter, W.P. Reidy, W.A. Sheehan, T.F. Zehnpfennig, "The Design and Flight Test of a 30 KW Rocketborne Electron Accelerator Module (EXCEDE II Test)", HAES Report No. 22, AFCRL-TR-75-0379, Visidyne, Inc., VI-289, (15 July 1975)

14 McEntire, R.W., R.A. Hendrickson and J.R. Winckler, "Electron Echo Experiment 1, Comparison of Observed and Theoretical Motion of Artificially Injected Electrons in the Magnetosphere", J. Geophys. Res., 79, 2343 (1974)

15 Winckler, J.R., "Probing the Magnetosphere with Artificial Electron Beams", Space Research (in press)

16 Huber, W.B., "Design and Fabrication of Satellite Electron Beam System", AFGL-TR-76-0184

17 Masek, T., "Satellite Positive Ion Beam System", AFGL-TR-78-0141

18 Cohen, H.A., Presented at 3rd Spacecraft Charging Technology Conference, USAF Academy, Colorado Springs (1980)

19 Purvis, C.K., R.O. Bartlett, and S.E. DeForest, "Active Control of Spacecraft Charging Technology Conference", C.P. Pike and R.R. Lovell, eds. AFGL-TR-77-0051, NASA TMX-73537 (1977)

20 Goldstein, R., "Active Control of Potential on the Geosynchronous Satellites ATS-5 and ATS-6" in Proc. of Spacecraft Charging Technology Conference, C.P. Pike and R.R. Lovell, eds. AFGL-TR-77-0051, NASA TMX 73537 (1977)

21 Beghin, C., "Plasma-Physics Investigations on the First Spacelab Payload", ESA Journal 3, 123 (1979)

22 Banks, P.M., Utah State University, private communication

23 Obayashi, T., "Space Experiments with Particle Accelerators: SEPAC - SEPAC Program for First Spacelab Mission" Solar Terr. Envir. Res. in Japan 2, 159 (1978) and private communication

APPENDIX A

SUBSIDIARY CONSIDERATIONS FOR SHUTTLE-BASED PARTICLE BEAM EXPERIMENTS

A.1 International Treaties Effecting the Use of Beams in Space: The U. S. Arms Control and Disarmament Agency published in 1980 a document entitled "Arms Control and Disarmament Agreements, Text and History of Negotiation"[A.1]. A study of this document reveals that only two of the treaties have some relevance to the problem at hand.

The Outer Space Treaty[A.2] concerns itself with principles governing the activities of studies in the explorations and use of outer space, including the moon and other celestial bodies. Article I of this treaty specifically calls for freedom of scientific investigation and encourages international cooperation. Article VII, shown in its entirety in Figure A.1, makes the U. S. responsible for any collateral damage that a particle beam emitted from any of its spacecraft may cause to another object in space.

The Environmental Modification Ban[A.3] concerns itself with modifications having widespread, longlasting, or severe effects as a means of destruction, damage, or injury. Article III specifically states it shall not hinder the use of environmental modification techniques for peaceful use and calls for the facilitation of exchange of scientific and technological information on the use of environmental modification techniques for peaceful purposes. We deem that the propagation of a particle beam through space does not constitute a modification of space. While a beam may effect some particles and fields in a limited portion of space, it does not produce widespread or long-term modification and is similar in this regard to the propagation of a radiowave or the passage of a spacecraft.

A.2 Environmental Impact: International - The Environmental Modification Ban[A.3] concerns itself with widespread, longlasting modifications of space.

National - Executive Order Number 12114, signed by the President on January 4, 1979, calls for implementation of the National Environmental Policy Act (NEPA) in compliance with the regulations of the Council on Environmental Quality (CEQ). The executive order is concerned with modifications resulting in significant impact on the human environment.

Each State Party to the Treaty that launches *or procures the* launching of an object into outer space, including the moon and other celestrial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to *its natural or juridical persons by such object or its component* parts on the Earth, in air space or in outer space, including the moon and other celestial bodies.

Figure A.1 : Article VII of the Outer Space Treaty.

In response to this directive, the various governmental departments have published proposed procedures for implementing this order. The Department of the Air Force Policy[A.5] has established catogories of activities giving qualifications for automatic exclusion from environmental impact considerations. Where such automatic exclusion is not clearly evident, AF form 813 is used to describe the proposed action and its possible alternatives. The Environmental Protection Committee (EPC) evaluates this form and makes appropriate recommendations. It is our opinion that the planned experiments would have environmental impact of insufficient magnitude to require action beyond the use of AF Form 813.

A.3 Safety Considerations: While the procedures for the utilization of the Space Transportation System are evolutionary in nature and still subject to change, NASA has established some procedures and documented these in a number of publications, most of which are updated at irregular intervals. These documents provide general guidance and requirements for STP payloads. References A.6 - A.15 are those documents which we feel are particularly applicable to the design of an STP charge-ejection payload.

Payloads are currently being built in accordance with these guidelines and they permit the choosing of materials, components, etc. in compliance with the safety requirements of shuttle flights. Specific safety factors depending on the nature of the experiments proposed to be developed here must, of course, be handled on an individual basis. Spacelab I, carrying a number of particle accelerators, has broken the ground for such payloads.

It may be necessary to eject beams in a direction where the direct particle return will miss the vehicle. This will limit the pitch angle of ejection to a cone which excludes the normal to the magnetic field. Mechanical stops to force such rejection in case of misalignment can easily be incorporated into the beam emission system[A.15]. For currents and voltages as low as those envisioned on Payload I (see Section 4), the precautions developed for Spacelab I will be adequate. At the higher current and voltages that are to be employed, we propose these experiments to be conducted from a free-flyer or tethered subsatellite which will of course alleviate much of the safety consideration.

REFERENCES

A.1 United States Arms Control and Disarmament Agency, 'Arms Control and Disarmament Agreements", Text and Histories of Negotiations publication 105, USACDC, Washington, D.C., (August 1980)

A.2 Reference A.1, p. 51.

A.3 Reference A.1, p. 193.

A.4 Federal Register 43, p. 55978

A.5 Federal Register 44, p. 44118

A.6 "Space Transportation System User Handbook", U.S. Government Printing Office, (June 1977 and periodic updates)

A.7 "Spacelab Payload Accommodation Handbook", SLP/2104 European Space Agencies, including:
Appendix A - Avionics Interface Definition,
Appendix B - Structure Interface Definition Module,
Appendix C - Structure Interface Definition Pallet

A.8 "Space Shuttle System Payload Accommodations", JSC 07700 Lyndon B. Johnson Space Flight Center, Houston, Texas, Vol. XIV

A.9 "Space Shuttle System Payload Safety Guidlelines Handbook", JSC 11123, Lyndon B. Johnson Space Flight Center, Houston, Texas

A.10 "Implementation Procedure for STS Payload System", JSC 13830, Lyndon B. Johnson Space Flight Center, Houston, Texas

A.11 "Safety Measurements", SJSC 13830, Lyndon B. Johnson Space Flight Center, Houston, Texas

A.12 "Safety Policy and Requirements", NHB 17007, NASA, Washington, D.C.

A.13 "Spacelab Mission I Experimental Descriptions", NASA-TM-78173 and ESA/FSLP-EX-001, George C. Marshall Space Flight Center

A.14 "Design Criteria for Controlling Stress Corrosion Cracking", MSFC-HDBK 527, George C. Marshall Space Flight Center, Alabama

A.15 "Materials Selection Guide for MSFC Spacecraft Payloads", MSFC-HDBK 527, George C. Marshall Space Flight Center, Alabama

A.16 William Baker, Goddard Space Flight Center, private communication

APPENDIX B

SPACE TRANSPORATION SYSTEM (STS)

The proposed study to develop charge ejection payloads is based on STS usage and the following ground rules:

1. The accelerators, diagnostics, and other ancilliary hardware will fly on Space Test Program (STP) sponsored missions; i.e. they will be part of a dedicated DoD funded shuttle mission.

2. The experimenter will be provided with mission support and mission support equipment.

This study limits itself to the on-orbit environmental conditions to be expected at altitudes from 200-1000 km. It further considers only the problems inherent in the experimental hardware unique to the charge ejection mission and this hardware's interface with "normal" mission support equipment. Therefore, the availability of the shuttle and its mission support is assumed.

It is also assumed that Sortie Support System (SSS) components as described in the following will be available for use by the experimenter.

The Sortie Support System is the following:

(1) Sortie Support Equipment (SSE) consisting of the flight equipment required for the mechanical support, electrical power, communications, data handling, experiment orientation, thermal control, flight crew interfaces, and computer software;

(2) Support and Test Equipment (STE) consisting of the equipment required to test, support, and maintain the SSE;

(3) Astronaut/Payload Specialist Training Equipment (ATE) consisting of all the equipment required to train Orbiter flight crews and support personnel in the use of the SSE.

B.1 Sortie Support Equipment (SSE): The SSE, shown in Figure B.1, includes the Orbiter cargo bay equipment used to support the experiments and the aft flight deck equipment used to control and operate the experiments.

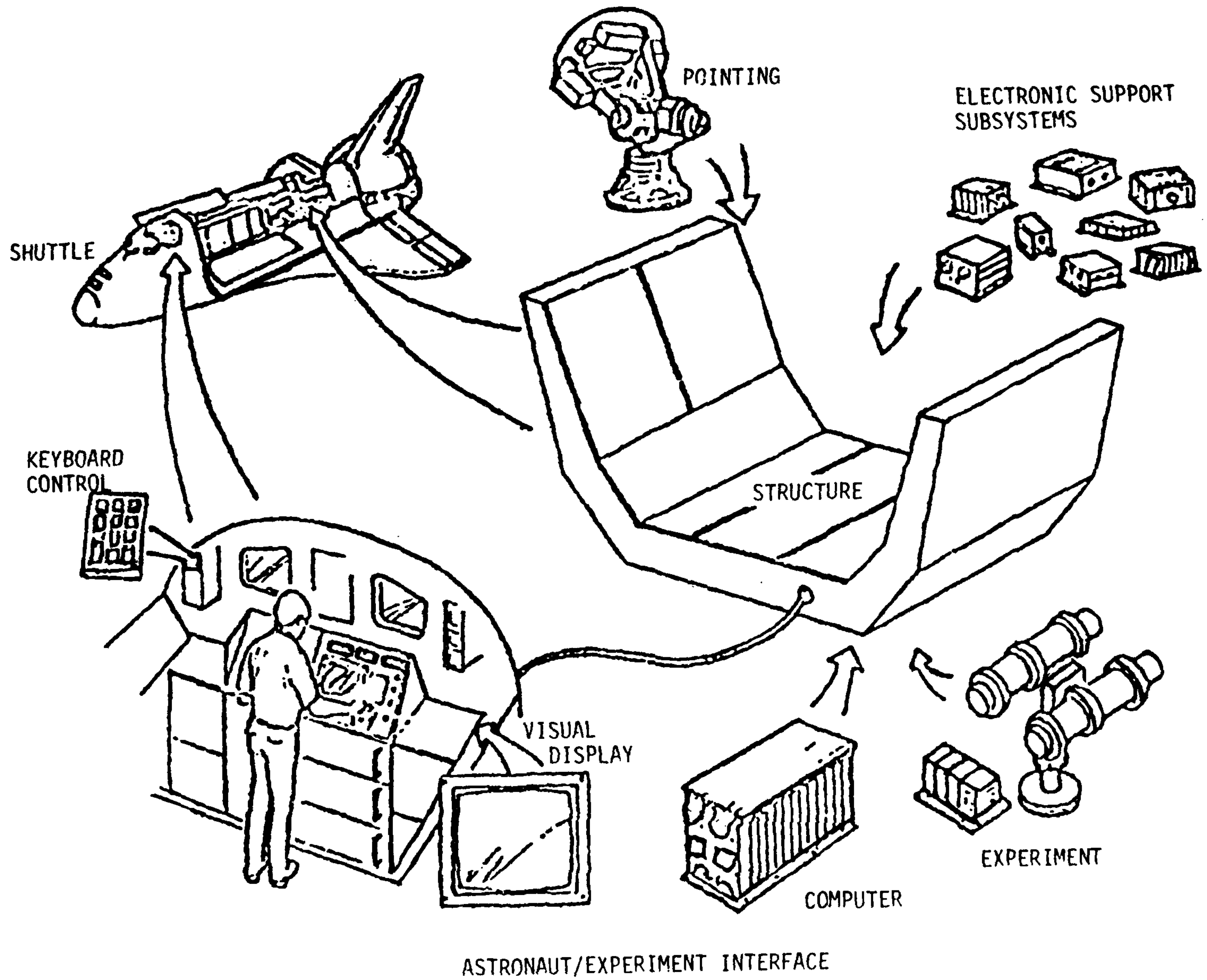

Figure B1:Sortie Support Equipment (SSE).

The SSE cargo bay structure will consist of modular pallets on which the experiments will be mounted for their direct exposure to space. The modular pallets will accommodate an experiment complement up to 12 feet in diameter, 15 feet long, and weighing 6500 pounds. Appropriate handrails, footrests, and attach points will be provided for astronaut extravehicular activity (EVA) about the pallet(s).

The SSE electrical power subsystem will receive its primary power from the Orbiter Power Bus. The subsystem will be capable of handling the full 7kW power capability of the Orbiter Bus and provide three types of electrical power: unregulated 28VDC; regulated 28VDC; and 115V (rms), 400 Hertz, 3-phase power. The pallet system will also be capable of providing 60 kilowatt-hours of internal electrical energy independent of Orbiter electrical power if required by the experimenter or for autonomous operation.

A communications and data handling subsystem will provide command, telemetry, data routing, storage, security, caution, and warning processing. All ground communication with the SSE will be relayed to and from the Satellite Test Center (STC), Sunnyvale, California via the NASA Space Tracking and Data Network (STDN)/Tracking and Data Relay Satellite System (TDRSS) and through the Orbiter. The design will allow for the future addition of an RF capability to communicate directly with the STC through the Remote Tracking Stations (RTS) worldwide. The command section will convert NASA/STDN binary command data to Space Ground Link Subsystem (SGLS) ternary format and then decode, store, transfer, and execute ground and Payload Specialist initiated commands. The telemetry section will collect, encode, multiplex, and format experiment data for transmission to the ground and/or recording. Tape recorder storage and playback of experimental data will also be provided for processing and display to the Payload Specialist. Special processing operations will include the fundamental mathematical operations, data averaging, ratioing and Fast Fourier transformations.

An orientation subsystem will provide a gimbaled platform capable of performing all pointing functions required to orient sensors weighing up to 4400 pounds during on-orbit operations. Experiment orientation will be capable of being controlled by automatic and manual on-board and ground generated commands. The system will also be capable of accepting control sensor data inputs from the attached sensor.

The thermal control system will use the Orbiter-provided payload heat exchanger cooling system, capable of up to 8KW dissipation. The thermal control subsystem is capable of accommodating an additional experiment heat exchanger if required. Experiments which use cooled telescopes (optical and focal plane) will be required to furnish their own cooling for that purpose.

For the purpose of performing "quick-look" data analysis, and adjusting and controlling experiment operating modes, the SSE will provide the capability for the Payload Specialist to interact with the experiments, the SSE subsystems and ground personnel from the aft flight deck of the Orbiter. The Payload Specialist will have a display, a keyboard, switches and status indicators, a hand controller and a secure voice link with ground personnel. The CRT display will provide alphanumeric, graphic, and image formats for displaying experiment command, health, and status data; plotting sensor data; and viewing a scene derived from a TV analog or sensor digital video signal. Command switches to the SSE and experiments will provide backup mission critical commands. With the keyboard, the Payload Specialist will be able to initiate SSE and experiment commands and control the computation and resultant display of data. The hand controller will enable manual control and operation of the orientation subsystems' gimbaled platform for experiment/sensor pointing. Voice communications between the on-board stations of the Orbiter, the Payload Specialist on the aft flight deck, and the ground will be provided through the Orbiter Audio Central Control Network.

B.2 Support and Test Equipment (STE): The STE will perform those functions required to inspect, test, evaluate, calibrate, measure, assemble, disassemble, handle, transport, safeguard, store, service, repair, and maintain the SSE during all phases of Sortie Support System operations.

B.3 Astronaut/Payload Specialist Training Equipment (ATE): The ATE will perform those functions required for training of the Orbiter flight crew including the Payload Specialist, the Air Force contractor mission integration personnel and experiment agency personnel. The training will be designed such that these personnel will acquire the necessary skills and ability to interact, operate, and maintain the SSE and experiments during mission operations in orbit.

The ATE will consist of a mock-up of the aft flight deck of the Orbiter with sufficient fidelity to provide a realistic training environment. The ATE will interface with the experiments through the standard SSE flight hardware. Experiment operation and data output will be obtained using the actual flight hardware if available or by computer simulation. Orbiter flight data will be provided by simulation. Training on the use of the SSE with the ATE will be accomplished by the prime SSS contractor who will provide the facility and personnel to conduct the training.

B.4 Experiment Integration: The integration of the experimental hardware with the Shuttle would proceed in accordance with a number of tasks as indicated in Figure B.2. It is not envisioned that the DoD experimenter will be in a position to participate in Levels I through III of the Integration Task. On the other hand, it is clear that only the experimenter can be responsible for Level V integration. It is further assumed that he will provide experimental components designed to be compatible with the SSE centrally procured and made available by the STP. Thus, the experimenter must, as part of his payload integration, provide his own equipment, should the support equipment be insufficient for his requirements. We visualize, for instance, that for later payloads the power provided might have to be supplemented by batteries which would constitute part of the experimental payload.

Level IV integration responsibility could reside either with the experimenter or STP. It is estimated that the cost for Level IV integration of the first payload is about $2,000,000.

B.5 Utilization of Complimentary Hardware: In order to minimize cost and to maximize reloadability, it is planned to utilize hardware developed for other shuttle experiments where appropriate. NASA-planned reflyable scientific components which have utility of particular interest to this program include a plasma diagnostic package and a low light level television (LLLTV). It was shown in Section 3 that the NASA plans for shuttleborne particle experiments will not satisfy AF requirements. Nevertheless, diagnostic equipment developed for the NASA sponsored work can be used directly or with little modification in the AF program.

INTEGRATION TASKS		LEVEL
INTEGRATE INSTRUMENTS INTO EXPERIMENTS	INSTRUMENT ASSEMBLIES	V
INTEGRATE EXPERIMENTS & CARRIERS INTO PAYLOAD ELEMENTS		IV
INTEGRATE PAYLOAD ELEMENTS INTO CARGO ELEMENTS		III
INTEGRATE CARGO ELEMENTS INTO CARGO		II
INTEGRATE CARGO INTO ORBITER		I

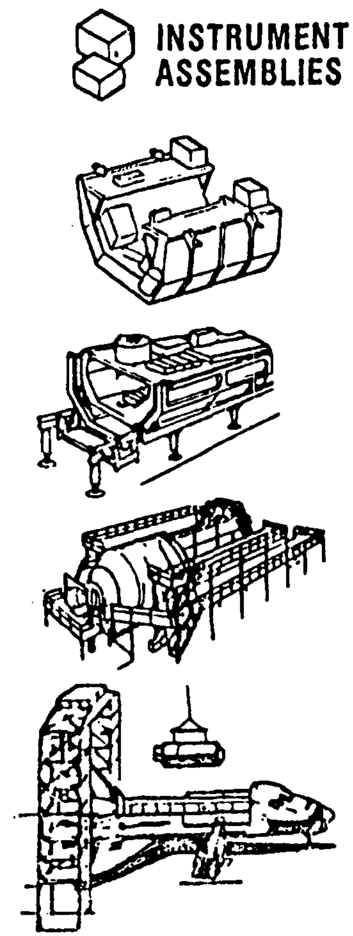

Figure B2: Payload/Cargo Integration Definitions.

The first Space Shuttle contains an ejectable plasma diagnostic package developed by the University of Iowa. This package will not be recovered. However, current NASA plans call for the development of a Recoverable Plasma Diagnostic Package (RPDP). The plans for this package will permit some additional instrumentation as well as modification of the core instruments. The following describes the core instrumentation.

The RPDP is a fully instrumented, ejectable, and recoverable unit with flight and ground support systems so that it can be utilized while attached to the Orbiter Remote Manipulator System, or tethered from the Orbiter, or as an Orbiter subsatellite up to ~200 km range with an operation time up to 200 hours from batteries. Core instruments on the RPDP are flight-proven hardware which provide diagnostics measurements of energetic particles (electrons and ions, 2eV to 50 keV), electromagnetic and electrostatic waves (5 Hz to 30 MHz), vector magnetic field signatures of current system ($>2\gamma$), vector electric field signatures associated with plasma flow and particle acceleration (>1 mV/m), thermal plasma ion composition and density (1-64 AMU, >1 cm^{-3}), thermal plasma electron density and temperature (10^2 to 10^7 cm^{-3}, 1×10^2 to 1×10^4K) and images of optical emission regions in UV (1100-170A) or visible (3900-6300A) wavelengths. Figure B.3 pictures this satellite and Table B.1 provides basic mechanical and electrical information.

The complexity of the planned experiments require that some diagnostics be performed at more than one point in space. We therefore propose the use of throw-away-detectors (TAD's). Such detectors are required to intercept ejected beams at more than one point in space, beams going in different directions, and beams of different or no charge in addition to electron beams. We visualize a simple device with relatively crude measurement capabilities of particle flux and energy as well as magnetic field direction. Since beam intercept occurs for only a short period of time, very little data handling will be required. By comparing the count rate in differently oriented solid-state detectors, directional data can be derived. In addition, a strobe light for accurate positioning and antennas for data transmission will be required.

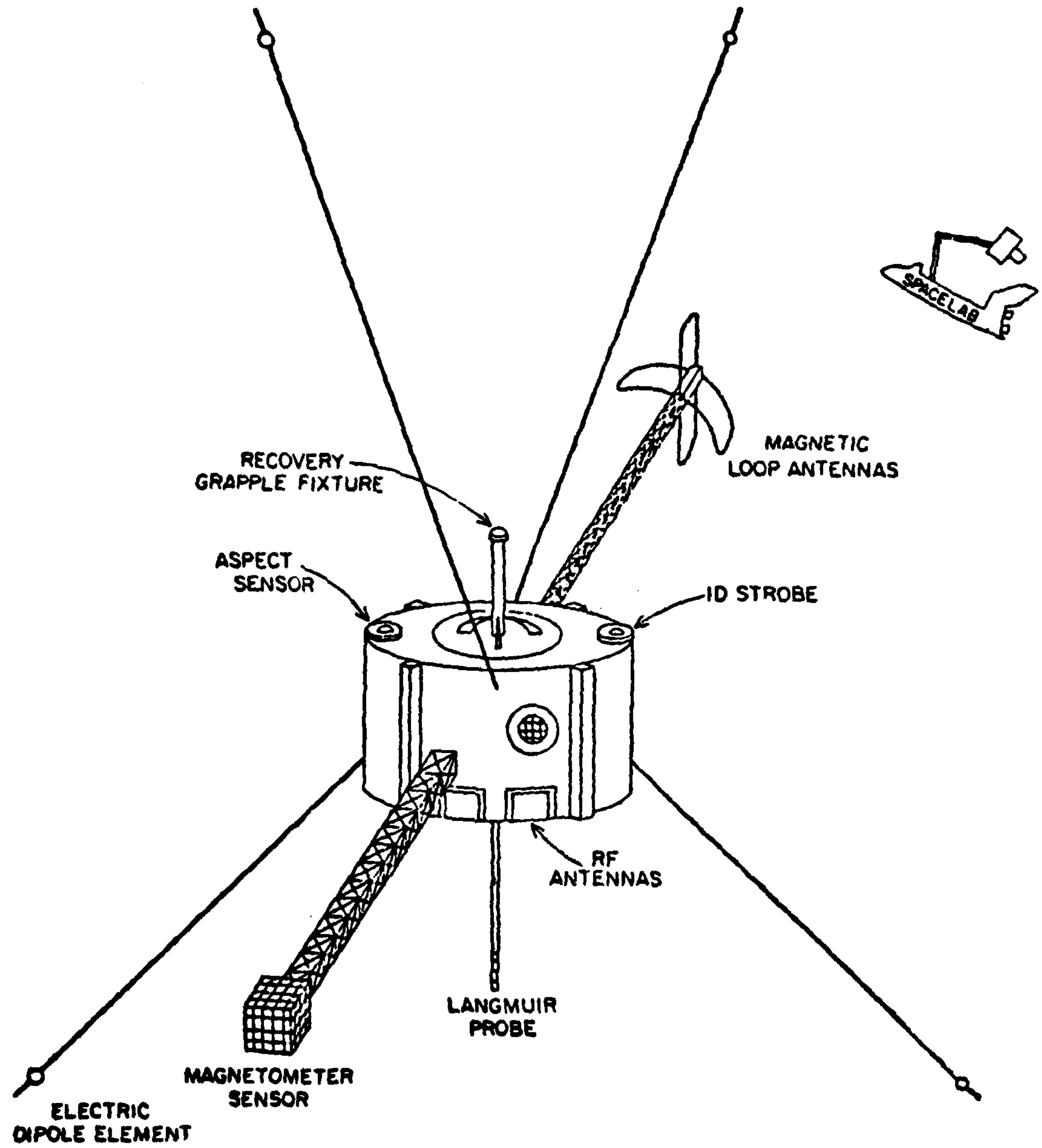

Table B.1

Recoverable Plasma Diagnostics Package (RPDP): Houses scientific instruments and subsystems on RMS and as subsatellite.	Size	107 cm dia x 66 cm high
	Weight	250 kg
	Energy	9 KWH from batteries
	Operating Life	100-200 hours at 90-45 watts
	Telemetry Up & Down. . .	400-402 MHz UHF band, ~1 watt
	Telemetry Range.	100-200 km
	Commands	32 for S/C functions & data mode
	Data System.	RCA 1802 µP based
	Antennas	4 of 15 m-tubular type/retractable
	Booms.	2 of 3m-telescoping/retractable
	Aspect	Star sensor, sun sensor, triaxial magnetometer for ±0.1° accuracy
	ID Strobe	1 or 2 @ 40 flashes/minute

FIGURE B.3

For the experiments in which the accelerators are not aboard the shuttle, i.e. Payloads 2, 3, 5, and 6, it will be desirable to utilize a tethered platform. This will make recoverability and subsequent reuse of the equipment easier. It will also permit the transmission of signals to the platform, as well as make data retrieval less complicated and expensive. Since this configuration will not be required for the first payload, engineering details for this concept can be postponed to a time when experience with STS tethered objects becomes available from other flights.